DESIGN AND DEVELOPMENT OF AUTOMATED TOKEN ASSEMBLY SYSTEM

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A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering (Honours) Mechatronics Engineering

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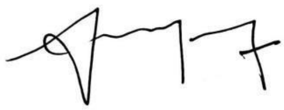
Universiti Tunku Abdul Rahman

September 2021

DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

Signature : 

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APPROVAL FOR SUBMISSION

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Date : 20 September 2021

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ABSTRACT

Considering the COVID-19 outbreak globally, assembly machines are relatively important for manufacturing sectors for mass production and process reliability. Human errors are the key factor that gives rise to diminishing the quality of the final product in the existing manual assembly operations. Considering this issue, it became apparent that the new assembly methods should be adapted. The aim of this project is to design an automated assembly system that is able to assemble the door gift. The automated assembly system is made up of three body magazines, a key magazine, linear actuators, a gripper, and a main assembly acrylic board. Aluminum profiles are implemented as the machine frame due to their extraordinary flexibility and structural strength. This industrial-based project is linked with Greatech Integration (M) Sdn. Bhd. The assembly machines provide a significant contribution to the field of industrial automation and robotics with the integration of an automated assembly system that can assemble door gifts. The future implementation of the automated assembly system offers leading advantages in refilling components as the pillars and drum can be removed with the empty magazines. Hence, the objectives of enhancing the reliability of assembly lines with lesser human labor and time required are achieved.

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LIST OF SYMBOLS / ABBREVIATIONS

m	mass
a	acceleration imparted by robot
g	gravity acceleration
μ	coefficient of friction between object and gripper’s jaw

ABS	Acrylonitrile Butadiene Styrene
ASME	American Society of Mechanical Engineers
CAD	Computer-aided design
CAM	Computer-aided manufacturing
CNC	computer numerical control
CPU	central processing unit
D.O.F	degree of freedom
EPU	Economic Planning Unit
FDM	Fused Deposition Modeling
GD&T	Geometric Dimensioning & Tolerancing
IR	infrared
ISO	International Orgranization for Standardization
I/O	input/ output
IPC	industrial personal computer
MIDA	Malaysian Investment Development Authority
PETG	Polyethylene Terephthalate Glycol
PLA	Polylactic Acid
PLC	programmable logic controller
SME	small and medium enterprise
2D	2-Dimensional
3D	3 dimensional

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CHAPTER 1

INTRODUCTION

1.1 General Introduction

Considering the COVID-19 outbreak globally, assembly machines are relatively important for manufacturing sectors for mass production and process reliability. It can be proved by the expected rising market trends of assembly machines in the United States as shown in Figure 1.1. According to the Global Market Insights Report (2019), the market revenue of the assembly machine is expected to attain USD 9 billion by 2025. In other words, automated assembly systems are adopted in most of the manufacturing industries these days to provide efficient and reliable assembly processes.

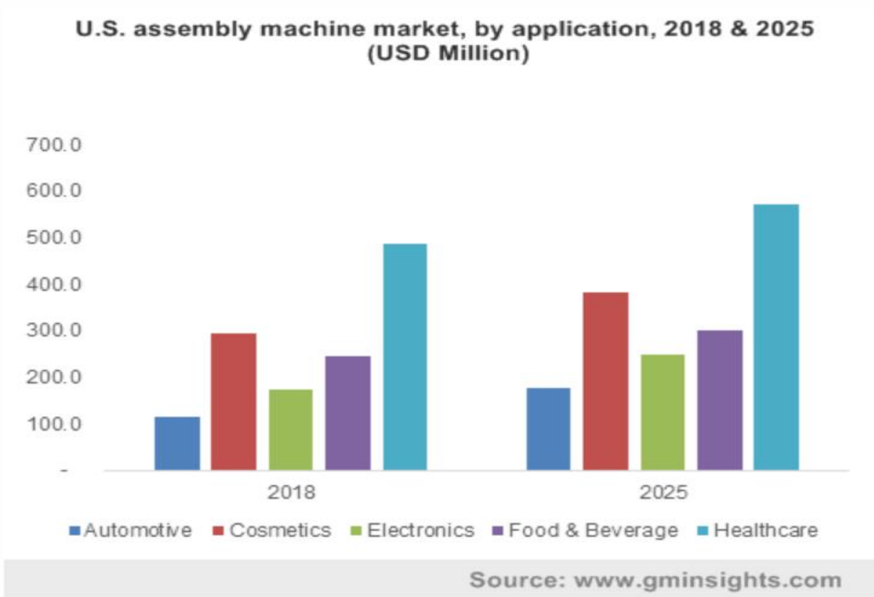


Figure 1.1: Market Trends of the Assembly Machine in the U.S. (GMInsights, 2019)

Meanwhile, the government of Malaysia is aspired to promote Industry 4.0 technology in industries. In view of the report of the Eleventh Malaysia Plan by the Economic Planning Unit (EPU), the government is focused on accomplishing productivity enhancement and reduce the reliance on capital and labor inputs. (The Eleventh Malaysia Plan, 2015) Adopting automation is one of the solutions to accomplish this mission. According to Dato' Azman Mahmud (2018), the CEO of MIDA, there are up to 120 companies in Malaysia that are able to manufacture high precision handling systems such as ViTrox Corp Bhd and Walta Group. These companies aimed to create a smart factory environment by implement automated assembly lines in their production. This progress certainly speeds up Malaysia's journey to becoming a digital society.

In fact, the integration of automation aims to boost efficiency, productivity, and quality, with lesser manpower and human errors at the same time. (Hudedmani, Umayal, Kabberalli & Hittalamani, 2017) Some human errors that possibly occur during the manual assembly process comprise part missing or misalignment in assembly, inconsistency, which causes defects on assembled pieces. Hence, the implementation of old manual assembly systems is gradually declined over the years. Nevertheless, the assembly processes of some SMEs in Malaysia are still in the manual assembly stage. Therefore, these companies are encouraged to develop an automated system to empower a digital society. Despite the fact that the previous manual assembly method provides a significant contribution in manufacturing for decades, yet there is still a great opportunity for productivity gains with fully automated techniques. Hence, the goal of this project is to design an automated assembly system that can assemble the door gift.

1.2 Importance of the Study

This project presents a feasibility study on automated assembly machinery design and automation control systems. Besides, it provides a significant contribution to the field of industrial automation and robotics with the integration of an automated assembly system. Consequently, productivity and product reliability can be assured with the reduction in errors and variability.

1.3 Problem Statement

According to Torres, Nadeau, and Landau (2021), human errors are the major factor that leads to a diminishing in the quality of the final products in manual assembly operations. Common human faults in manual assembly lines include improper installation, missing components, or not fitting connections. The occasion of human errors might be due to workers' operational environment factors, for instance, pressure, motivation, memory, or personal character. (Báez, Rodríguez, Limón & Tlapa, 2014) Heavy workload and insufficient rest time could affect the workers' capabilities and alertness, which possibly lead to a high risk of human errors. (Saptari, et. al, 2014) Apart from that, complex assembly processes will result in longer cycle time, the excess cost required, and a reduction in productivity. Considering these issues, it became apparent that the new assembly methods should be adapted. The evolution of the automated assembly system tends to improve the manufacturing assembly line in an effective way.

1.4 Aims and Objectives

This project aims to design an automated assembly system that is able to assemble the door gift.

The objectives of this project include:

1. To apply knowledge learned in Sensors and Instrumentation in sensor selection.
2. To apply Geometric Dimensioning and Tolerancing to define the engineering tolerances in the 2D drawing.
3. To implement mechanical engineering design skills in mechanical component selection and machine design.
4. To utilize 3D modeling skills learned in machine design.

1.5 Scope and Limitation of the Study

The scope of the project is to design an automatic token assembly machine. 3D modeling software, Solidworks is used to design the machine components assembly. Besides, Geometric Dimensioning and Tolerancing (GD&T) is applied to define the engineering tolerances. The functionality of the machine will be tested by using 3D simulation software due to the limitation of in-house facility for functional testing. Once the detailed design is finalized, the 2D machining drawings will be produced and sent to a company from the industry for evaluation and comments. The commented copies of the 2D drawing will be studied and an improved version of the drawings will be sent to the same company for further feedback and fabrication.

1.6 Outline of the Report

There are a total of six chapters in this report. Chapter 1 provides an overview of the study. It begins with a general introduction, followed by the importance of the study, problem statement, aim and objectives, scope and limitations of the study, and the organization of the report. In this chapter, the motivation and scope for the project are clearly defined. The overall outline of the report is described.

The second chapter is the literature review and background study of the related topics. The coverage of the second chapter includes the review of existing automation assembly machines and automation control systems along with the mechanical and electrical elements of automation.

Chapter 3 introduces the ideas and the methodology of the work plan. This chapter presented the flow chart about the method applied in this project and the project planning Gantt chart to monitor the progress. The duration and schedule of the workflow are clearly described. Furthermore, the flow chart of the mechanical design process and the 3D printing process is clearly defined.

Chapter 4 comprises the door gift design and the automated assembly system design. The subsystems and components of the machine are clearly described with the attached technical drawing.

Chapter 5 presents the design revision, design validation, and design optimization of the components. This is the chapter that discloses the success and failure of the design. Apart from that, this chapter discussed the problems encountered while conducting the project and the measures applied to these problems. A procurement list of the purchased components is attached in the last subtopic.

Last but not least, the final chapter summarises the conclusion of the entire report and project.

CHAPTER 2

LITERATURE REVIEW

2.1 Automated Assembly Systems

Groover (2015) defined an automated assembly system as a series of automated assembly executions which are capable of combining various parts into a single entity. It is a fully automatic system with the combinations of numerous manufacturing processes in respective workstations. The main elements of the automated system comprise power to execute processes, programs of instructions to control processes, and control systems to activate commands. (Groover, 2015) The complete assembly process can be performed with multiple subsystems such as (i) part feeding devices for parts alignment, (ii) machines for assembly operations, (iii) work handling systems to transfer parts between workstations, and (iv) a complete automation control system. An automated assembly system is able to provide high efficiency, productivity, and quality assembly operation without manpower.

The configuration of the automated assembly systems can be split into several types, which are in-line stations, dial-type stations, carousels, and single stations. (Groover, 2015) The layouts of these configurations are shown in Figure 2.1.

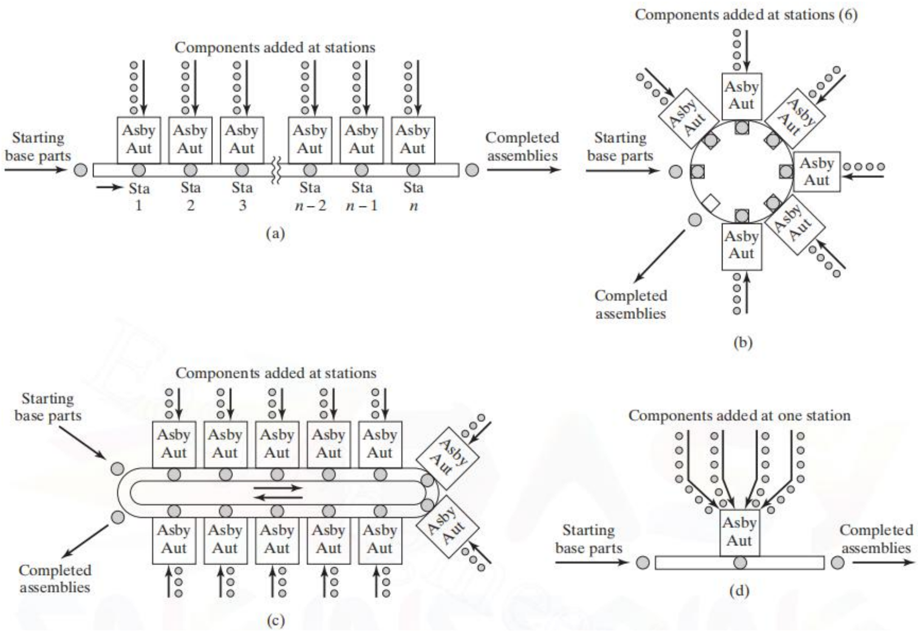


Figure 2.1: Physical Configuration of Automated Assembly System (Groover, 2015)

Several literature reviews on assembly machines were carried out as these studies have contributed a significant contribution to automation assembly systems. Wang, Pang, Cai, and Cui (2018) designed an automated assembly system of fuel tank overturn valves as shown in Figure 2.2. The system is designed in carousel configuration which is made up of several assembly workstations, covers and guarding for machines, a vibratory feeding bowl, and the Programmable Logic controllers (PLC) control system. This study presented the stability and the reliability of this automated overturning valve assembly in accomplishing assembly tasks. The defective product issues are successfully solved with the integration of this system.

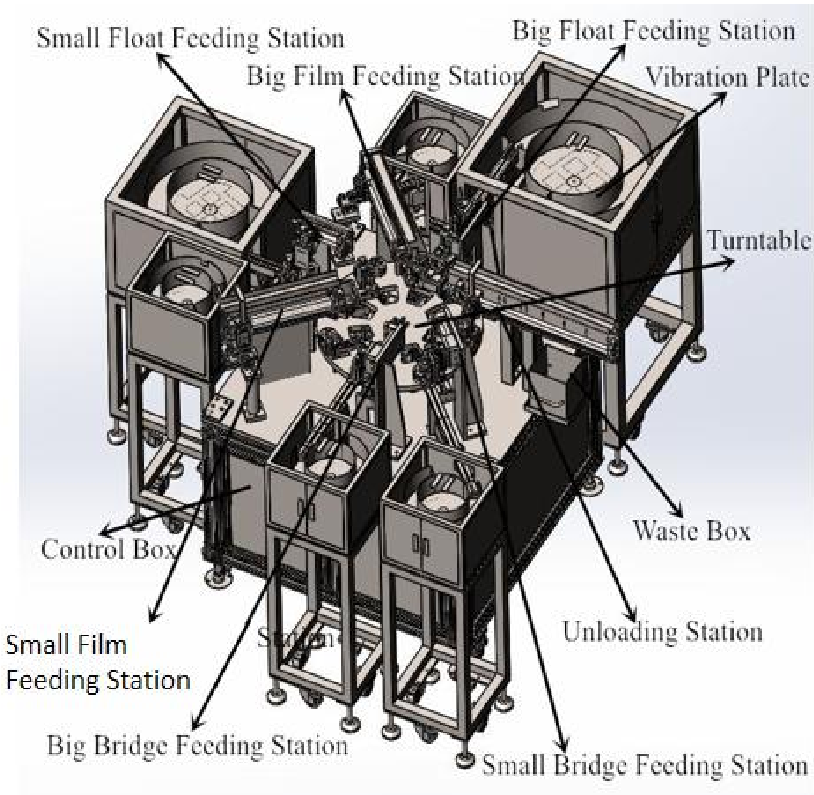


Figure 2.2: Automated Assembly System of Overturn Valve (Wang et. al, 2018)

Besides, there are few researchers who designed the automated assembly machine for the harness connector to replace the current manual assembly methods. (Veigaa, Campilhoa, Silva, Santosa, and Lopesa, 2019) The system as shown in Figure 2.3 consists of (i) three vibratory devices for feeding purposes, (ii) a rotary table as the central component of the equipment, (iii) three assembly stations to assemble the harness connectors, and (iv) conveyors to transfer the product. This design has successfully accomplished the objectives of automating the raw material feed, implementing grippers to automate the assembly process, and performing monitoring and inspection control to secure the product's quality.

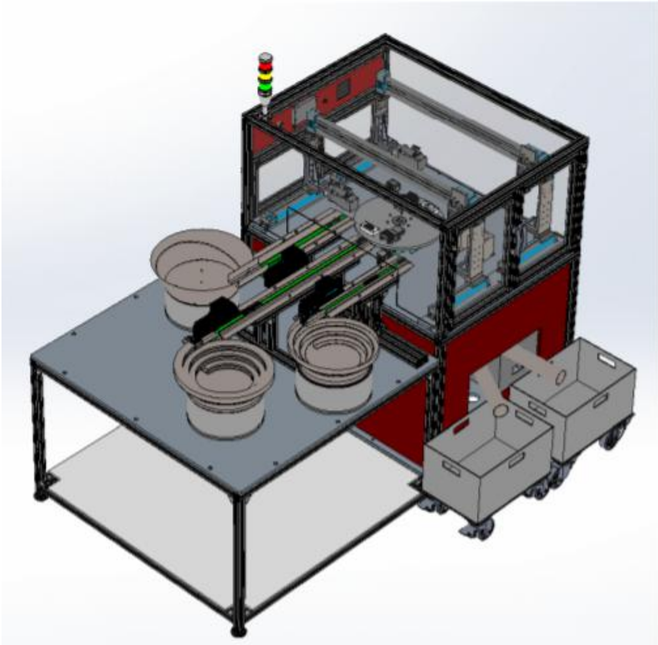


Figure 2.3: Automated Assembly Machines for the Harness Connector (Veigaa, et. al, 2019)

2.1.1 Summary

Based on the literature studies above, both automated assembly systems were designed to replace manual assembly techniques. In the first design by Wang, et. al (2018), some defects of the products include film superposition, location deviation, and loss of bridges tend to occur in the manual assembly operations. The problems that occurred in the manual assembly techniques of the second study are also due to human errors. (Veigaa, et. al, 2019) The repetitive tasks in the manual assembly will possibly lead to errors and reduction in productivity. Hence, the adoption of automation is necessary to solve these issues as accuracy and precision machining can be achieved by machines. In brief, the productivity and quality of the products can be enhanced by implementing task automation and eliminating human errors.

Despite both systems consist of part feeding devices and several workstations yet the configurations of both systems are different. The best option of the physical configurations is determined by the complexity of the assembly process in terms to achieve the lowest cycle time and greatest efficiency.

2.2 End Effector

The end effector, or gripper, allows the robot to grasp and control the work piece in a work cycle. (Groover, 2015) It is the hinge of the object's pick and place process. Besides, Groover (2015) mentioned that customization and fabrication of the design of the gripper are required for some specific conditions. Numerous types of industrial grippers like mechanical grippers, vacuum grippers, magnetized devices, adhesive devices, and some other simple mechanical devices like hooks provide wide applications in loading and unloading objects. Figure 2.4 shows the classification of grippers according to different actuation.

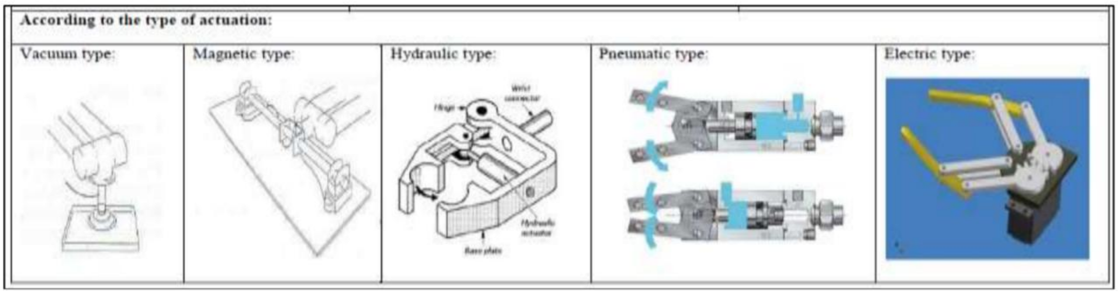


Figure 2.4: Classification according to types of Actuation (Raval, and Patel, 2016)

As stated by Raval and Patel (2016), the formula to calculate gripping force required at the jaws of a gripper can be derived as:

$$\text{Friction force, } F_f = \mu \times \text{gripping force} \geq \left(\frac{(a+g)\,m}{2}\right) \tag{2.1}$$

$$\text{Gripping force, } F_G = \frac{(a+g)\,m}{2\,\mu} = \text{Reaction force at Jaws} \tag{2.2}$$

where

F_f = friction force

F_G = gripping force

a = acceleration imparted by robot

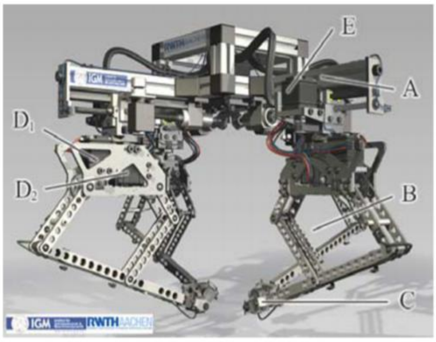
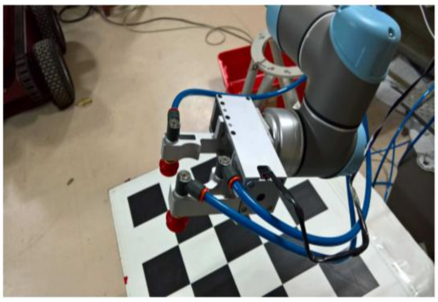
g = gravity acceleration

m = mass of object

μ = coefficient of friction between object and gripper's jaw

There have been relatively few research works on the application of grippers in robotics and pick and place systems. The diversity of the end effector design is heavily affected by the objects to be grasped. Table 2.1 shows the review summary of three different gripper designs.

Table 2.1: Review Summary of Gripper Design

Author (Year); Objective	Gripper Design
Nefzi, Riedel, and Corves (2006); To manipulate six d.o.f objects.	 Figure 2.5: Multi-finger Gripper PARAGRIP 2005 (Nefzi et. al, 2006)
Kumar, Majumder, Dutta, Jotawar, Kumar, Soni, Raju, Kundu, Hassan, Behera, Venkatesh and Sinha (2017); To automate picking and stowing system on different goods .	 Figure 2.6: Suction End-effector (Kumar, et al. 2017)
Wu, Li and Guo (2019); To pick objects with different shapes and sizes.	 Figure 2.7: E-Gripper (Wu et. al, 2019)

In the first study, the gripper is designed with multi-fingers to pick irregular parts securely. This model has leading benefits on simple gripping tasks, assembly, and sorting processes. The end effector design of the second study was the combination of a parallel jaw gripper and a suction system to grasp items that could not be picked by the jaw gripper. This gripper is expected to lift weight up to 2 kilograms. Bigger objects can be grasped if the space between fingers is increased. Wu et. al (2017) designed an endoskeleton E-gripper that is made from soft rubbers and seal rings to achieve high flexibility in picking different goods.

2.2.1 Summary

By comparing these models, the E-gripper is said to be the most flexible end-effector whereas the first model is more suitable for large industrial manufacturing applications. The second design is fit for irregular and light items. The end effector design has gradually improved over years. From the review studied, it can be concluded that the initial step in designing an end effector is to evaluate the grasping specification. As claimed by Sathishkumarl, Chandiran, Prabu, and Sakthivel (2017), the characteristics of gripper and object, gripper technology, gripper flexibility, and the operation cost are essential factors to be considered before choosing an end effector. In short, certain aspects like the shape, size, and form of an object urge the necessity of a distinct gripper design.

2.3 Industrial Motor

According to Arivazhagan, Menna, G/hiyot, Dana & Birhanu (2020), a stepper motor is fit for low speed, low acceleration, and low accuracy operations. The other upsides of stepper motors are it tends to be compact and economical. Contrarily, servo motors are the best options for precise and speedy systems. It offers a high rate of repeatability but it is more complex and costly. They are typically used in automated packaging production, solar maximum power point tracking system, or missile tracking applications. (Arivazhagan, et al., 2020) The comparison of the servo motor and the stepper motor is tabulated in Table 2.2.

Table 2.2: Comparison of Servo motor and Stepper Motor (Arivazhagan et. al, 2020)

Sl.no	Parameters	Servo Motor	Stepper Motor
1	Design cost	High	Low
2	Load carrying capacity	Can vary	Constant Load
3	Inertia with Load	Appreciably Good	Poor
4	Rated speed	High	Low
5	Axes of control	Complex	Quite simple
6	Efficiency	Excellent	Good
7	Capacity	Fractional to 15 HP	Less than 1HP
8	Maintenance	Frequent maintenance is required	Less maintenance Required

2.3.1 Summary

In summary, servo motors are preferable to apply on high speed and high torque automated assembly systems. It offers an undeniable performance on a highly-precision system. Stepper motor is well suited for low speed and low flexibility systems like medical and biotech manufacturing. Nonetheless, the torque and speed requirement, load mass, and cost are the important factors in motor selection. (Arivazhagan, et al., 2020)

2.4 Sensors in Automation

Groover (2015) claimed that sensors, or the transducers, are competent to convert physical variables from one to another form. In other words, sensors are used to convert the stimulus detected as signals and transfer it out as an output. Some common sensors used in industrial robotics are tactile sensors, proximity sensors, visual sensors, laser sensors, and encoders.

Recent research showed the installation of IR sensors on robotics suction-based end effectors to perform pick and stow operations. (Kumar, et al. 2017) These findings revealed the motivation to develop robotic systems that are capable to work in any environment without changing the previous infrastructure. The close view of the end effector is shown in Figure 2.8.

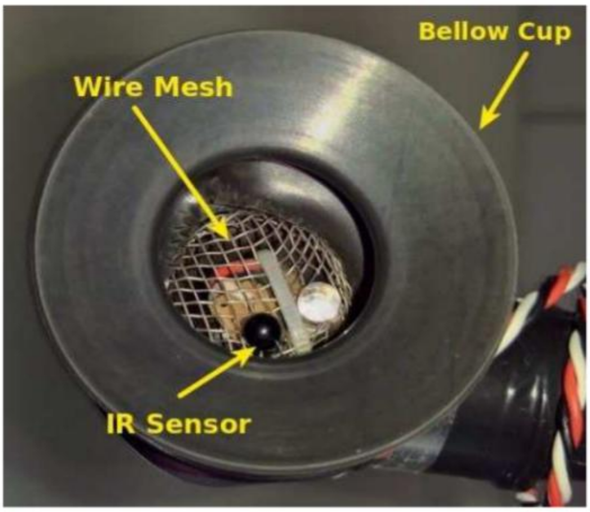


Figure 2.8: Close view of End Effector (Kumar, et al. 2017)

In another research by Sushmitha and Priyadarsini (2018), ultrasonic sensors are attached to the pick and place robots to detect obstacles. With this ability, it is suitable to be used in carrying goods without bump into obstacles. In order to enhance the performance of robots, they proposed that fire sensors and gas detectors can be added.

2.4.1 Summary

Although the pick and place robot design of both researchers is similar, yet different sensors are used. Both sensors served to detect distance range, however, the basis of IR sensors and ultrasonic sensors are slightly different. IR sensors used infrared right whereas ultrasonic sensors used sound waves for object detection. In short, the features such as types of stimulus, costs, and performance of the sensors should be considered to select the most appropriate sensors.

2.5 Automation Control System

In the world of industrial control systems, programmable logic controllers (PLCs) and industrial PC (IPCs) are the most famous control systems. According to Wilhite (2015), both controls have their own strategic positions that can be applied in various industries. Table 2.3 compares PLC and IPC in terms of applications, programming languages used, advantages, and disadvantages.

Table 2.3: Comparison of PLC and Industrial PC (Wilhite, 2015)

	PLC	IPC
Applications	i. Machine and process control.	i. Open-loop and closed loop-control. ii. Data processing and communication.
Programming Language	i. Ladder Logic. ii. Structured Text. iii. Functional Block diagram. iv. Sequential Functions Charts. v. Instruction list.	i. C. ii. C++. iii. Python. iv. Java and etc.
Advantages	i. Good maintainability and durable. ii. Greater process capability. iii. Simple integration. iv. Flexible and reliable.	i. Simple implementation, and configuration. ii. Able to multitask.
Disadvantages	i. Limited programming languages.	i. High acquisition and operation cost.

In industrial control applications, PLCs are more preferable for machine and control processes owing to lower costs required compared with industrial PCs. Apart from that, PLC is more reliable than industrial PC as system crashing usually happens on PC. Moreover, PLC has higher reliability on control with its real-time operating system. Although industrial PCs promote a variety of programming languages, yet PLCs are safer to use as they are less exposed to unauthorized access, which reduces the probability of virus or malware infection.

2.5.1 Programmable Logic Controller (PLC)

According to Groover (2015), PLC is described as a microcomputer-based controller of machine and process control. It comprises a central processing unit (CPU), programming appliances, I/O module, and power supply. (Shiv and Niwaria, 2018) PLCs are reliable in complex control operations as the controllers are made up of arithmetic and mathematical operation commands. Figure 2.9 shows the components of PLC.

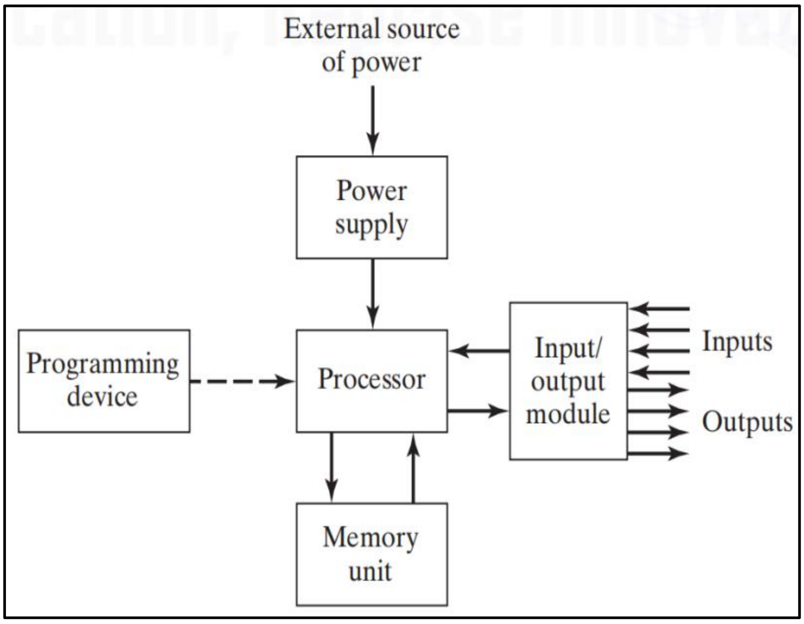


Figure 2.9: Components of PLC (Groover, 2015)

Among the programming languages developed in PLC, ladder logic diagram is most often used. The most basic ladder logic language was invented to replace logic control systems. (Patel, Sagar and Lad, 2019). In ladder logic diagrams, the contact is known as a general input device whereas the coils are the output device. Several contacts components are shown in Figure 2.10, namely normally open (NO), normally closed (NC), logic high out, and logic low out.

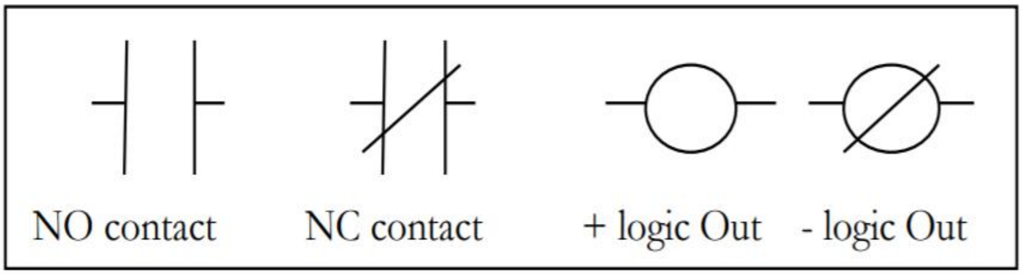


Figure 2.10: Ladder Logic Components (Hudedmani et. al, 2017)

Table 2.4 shows the review summary of other researchers on the implementation of PLC. Barz, Latinovic, Erdei, Domide, and Balan (2014) presented the employment of PLC Siemens CPU 313C in the manipulation of a three-axis robotic arm to replace CNC commands and to control the movement of robotic arms by means of stepper motors. Furthermore, a human-machine interface is used to monitor the movement of the robot arm.

Table 2.4: Review Summary of PLC Implementations

Author (Year)	PLC models	Application
Barz, et. al (2014)	PLC Siemens CPU 313C.	Manipulation of a three axis robotic arm.
Wang, Pang, Cai, and Cui (2018)	S7-1200 PLC.	Automated fuel tank valve assembly system.

Another research by Wang et. al (2018) conveys the application of PLC on controlling the automated fuel tank valve assembly system. The signals collected from PLC central processing station will activate the actuators like the servo motor, pneumatic cylinder, and dial divider. The architecture of the control mode is shown in Figure 2.11.

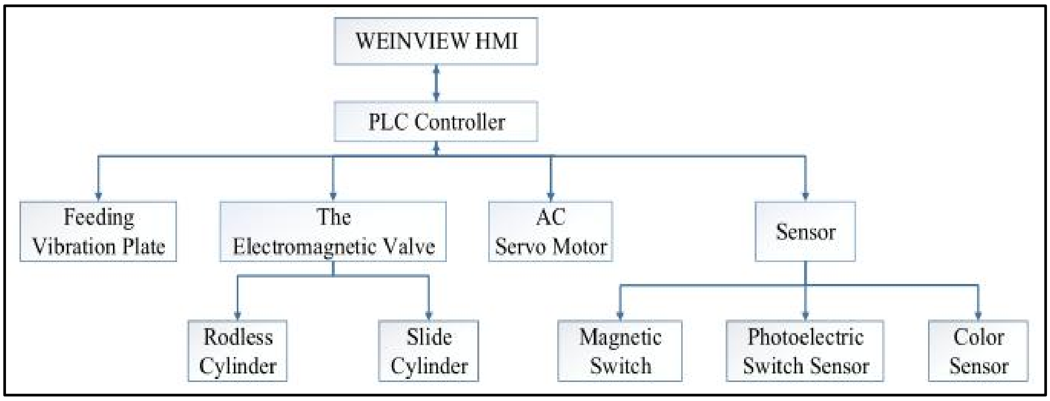


Figure 2.11: Structure of Control Mode (Wang et. al, 2018)

2.5.2 Summary

Despite PLC has its own leading advantages yet there are still several factors needed to take into consideration while performing PLC selection. For instance, amount and type of inputs and outputs, speed and power to drive the central processing unit (CPU), memory size required, code command and etc. (Hudedmani et. al, 2017)

2.6 Geometric Dimensioning and Tolerancing (GD&T)

Geometric Dimensioning and Tolerancing (GD&T) terminology has taken over the traditional method, coordinate dimensioning system since the 1940s to achieve a high level of precision. (Budynas and Nisbett, 2015) As the name implies, it is the standard symbol to describe the nominal geometry of parts and their acceptable variation. The International Organization of Standards (ISO) and American Society of Mechanical Engineers (ASME) standards are the global industrial standards that are generally implied in industrial. One of the ASME standards established is the ASME Y14.5 - 2009 Dimensioning and Tolerancing. Although both standards served the same objective in achieving standardization, yet different symbols and signs are used. (Budynas and Nisbett, 2015) Table 2.5 shows the differences between ISO and ASME standards.

Table 2.5: Comparison of ISO and ASME Standards (Morse, 2016)

	ISO Standard	ASME Standard
Sheet Size	A series paper size.	ANSI standard paper size.
Specifications vs. verification	Describe part geometry.	Presents identification of the links between design and verification.

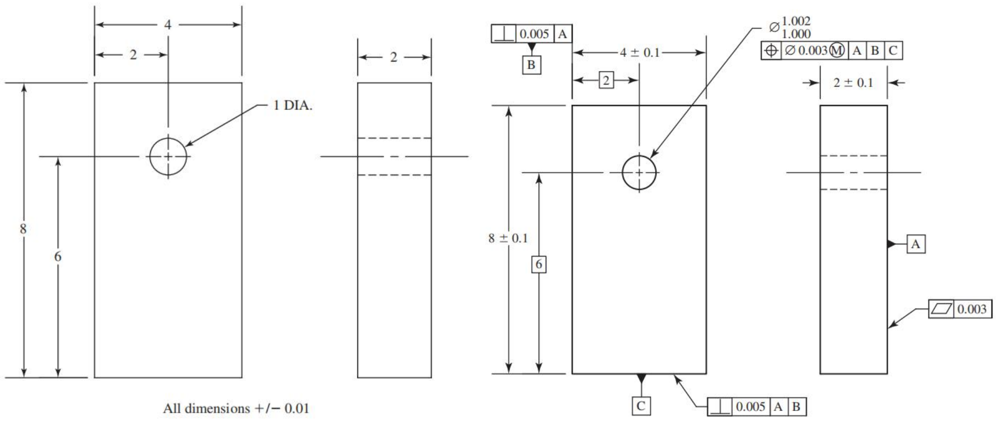
Geometric Dimensioning and Tolerancing (GD&T) serves a crucial role in 2D machining drawings. This terminology utilizes an international language of symbols based on their geometric characteristics. The geometric characteristics controls and symbols are tabulated in Table 2.6. The five major types of tolerance are form, profile, orientation, location, and runout. Datum referencing is required for most of the tolerance types except for form types.

Table 2.6: Geometric Characteristics Controls and Symbols and ASME Standards (Morse, 2016)

Type of Tolerance	Geometric Characteristic	Symbol	Geometric Attribute Controlled	Datum Referencing?	Material Condition Modifier Allowed
Form	Straightness	⏤	Form	No	Ⓜ Ⓛ or RFS
	Flatness	⏥			Ⓜ Ⓛ or RFS
	Circularity	○			RFS
	Cylindricity	⌭			RFS
Profile	Profile of a line	⌒	Location, orientation, size, and form	Optional	Ⓜ Ⓛ or RFS
	Profile of a surface	⌓			
Orientation	Angularity	∠	Orientation	Required	Ⓜ Ⓛ or RFS
	Perpendicularity	⊥			
	Parallelism	∥			
Location	Position	⌖	Location and orientation of feature of size	Required	Ⓜ Ⓛ or RFS
	Concentricity	◎	Location of derived median points or planes		RFS
	Symmetry	⌯			RFS
Runout	Circular runout	↗	Location of cylinder	Required	RFS
	Total runout	⌰			RFS

2.6.1 Geometric Dimensioning and Tolerancing (GD&T) of CAD/CAM

In the opinion of Budynas and Nisbett (2015), the integration of engineering design and manufacturing functions can be accomplished by CAD/CAM. The working terminology of GD&T on 3D models and 2D drawings are equal, the only dissimilarity is the general dimensions are not displayed in 3D models as all basic dimensions are by default. (Budynass and Nisbett, 2015) An example of CAD models before and after implementing GD&T is shown in Figure 2.12. It is apparent that the CAD model with GD&T conveys clearer information with detailed dimensions labeled. Detail dimensioning and tolerancing is critical in mechanical engineering drawing as it genuinely affects the accuracy and efficiency of manufacturing. Apart from that, the finishing quality of the parts can also be ensured if the dimensioning and tolerancing are defined precisely.



(a) (b)

Figure 2.12: (a) Before and (b) After implementing GD&T Terminology (Budynas and Nisbett, 2015)

2.7 Thermoforming

According to Ekşil, and Karabeyoğlu (2017), thermoforming applies heat and air pressure to the plastic sheet or film while manufacturing the product. The heating temperature relies heavily on the kind of plastic material. It is widely used in the packaging industry, automotive, electronics and etc. (Ekşil, and Karabeyoğlu, 2017) Jamil, Khalid, Zulqarnain, and Salman (2018) defined that the thermoforming process involves sheet clamping, heating, forming, cooling and trimming. According to the study, the plastic sheet will be securely clamped throughout the entire process, and heat will be transferred based on the machine and parameter settings.

Subsequently, the sheet will form the shape of the mold when it reaches the desired thermoforming temperature. Last but not least, the thermoformed product will be cooled and the unwanted part will be trimmed. The schematic of basic vacuum thermoforming by Ghobadnam, et. al (2015) is presented in Figure 2.13.

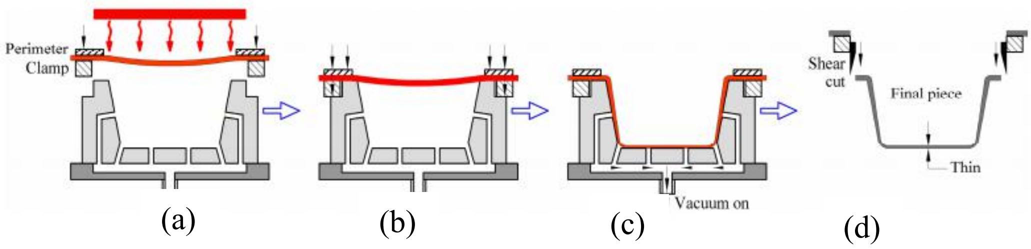


Figure 2.13: Schematic of Fundamental Vacuum Thermoforming (a) Heating, (b) Sealing or Pre-stretch, (c) Forming and Cooling, and (d) Demolding and Trimming (Ghobadnam, et. al, 2015)

Meanwhile, the output of the thermoformed product is heavily dependent on various factors for its success. Jamil, et. al (2018) have conducted an analysis study on the factors that affect that thermoforming process. The results showed that the factors arose from the material, mold, pre-stretching and mechanical support as shown in Table 2.7. From the investigation and analysis, Jamil, et. al (2018) mentioned that sheet thickness, sheet initial temperature, mold temperature and vacuum time are the four crucial factors in the thermoforming process.

Table 2.7: Factors that Affect Thermoforming Process (Jamil, et. al, 2018)

Sr. No.	Category	Variables
1)	Material	▪ Sheet thickness
2)		▪ Sheet pigmentation
3)		▪ Sheet size
4)		▪ Temperature uniformity
5)	Mold	▪ Vacuum bores or orifices
6)		▪ Mold surface
7)		▪ Mold temperature
8)		▪ Mechanical support temperature
9)	Pre-Stretching	▪ Vacuum box
10)		▪ Air temperature
11)	Mechanical Support	▪ Mechanical support form
12)		▪ Support materials
13)		▪ Support temperature
14)		▪ Support surface
15)		▪ Support height
16)		▪ Support vacuum speed
17)		▪ Support depth of action
18)		▪ Material variables when forming with support

2.7.1 Summary

In summary, thermoforming offers leading advantages over other manufacturing processes such as extrusion, injection molding, and blow molding. According to the study by Karabeyoğlu, Ekşi, and Erdogan (2017), thermoforming is comparatively cost-efficient as the cost of the initial tooling and the equipment are low. Apart from that, it provides outstanding design flexibility where the parts can be in a variety of forms and materials with different properties.

CHAPTER 3

METHODOLOGY AND WORK PLAN

3.1 Project Design Overview

The project design overview of this project includes multiple iterations such as conceptual design, detailed design, 3D modelling and 2D drawing. The flow chart as shown in Figure 3.1 depicts the work flow of each iteration.

3.1.1 Project Flow Chart

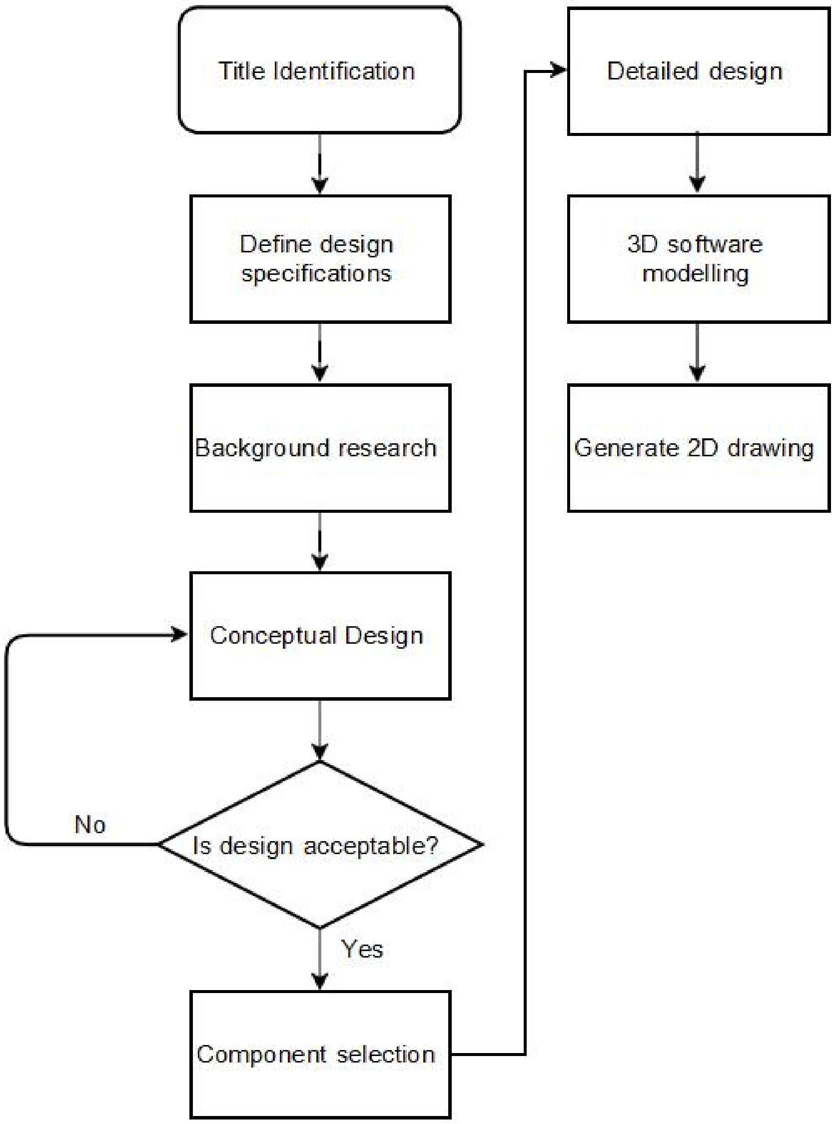


Figure 3.1: Project Flow Chart

The project workflow begins with title identification. Problem formulation is done in this stage where the aim and objectives of the project are clearly defined. The following stage is the design specification. It is one of the crucial steps where the desired solutions to achieve the user's expectations are identified.

The machinery design process can only be conducted prior to the fundamentals concept of automated assembly systems and automation control systems being studied. Hence, a literature review and background research on related topics are done.

Subsequently, the conceptual frameworks of automated assembly systems are drawn and modified several times to achieve the project's objective. Factors like cost, reliability, and performance are considered while designing the system.

Once the conceptual design is accepted, it will proceed to mechanical and electrical components selection. Then, the detailed design and the 2D drawing of the model are illustrated using 3D software - Solidworks.

3.1.2 Project Gantt Chart

Figure 3.4 and Figure 3.5 illustrate the detailed project schedule and tasks conducted throughout the first session and the final session of the final year project respectively. The total duration of this project is 28 weeks, which is from 18th January 2021 to 10 September 2021. It is divided into two sections that utilize similar project schedules with different door gift designs. The door gift to be assembled in the FYP 1 is the puzzle cube designed by Wildrose Builds. It is consists of three identical cubes that can form a square. The improved version of the door gift, Hexolon is designed and selected as the door gift to be assembled in FYP 2.

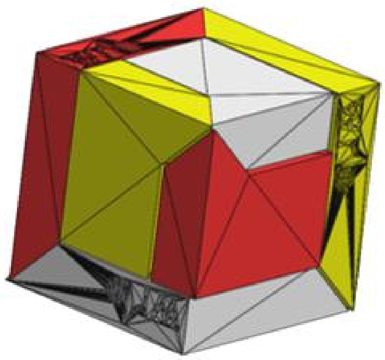


Figure 3.2: Puzzle Cube (Wildrose Builds)

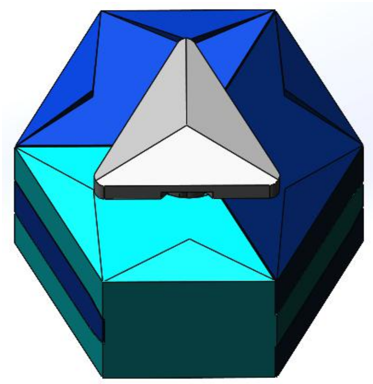


Figure 3.3: Hexolon

The tasks are divided into three main phases: research and problem formulation, design and evaluation, and report writing. During the first phase, some literature reviews and research related to automated assembly systems design are studied once the project title and objectives are identified. The scope of the research includes the working principles of automated assembly machines, industrial motors, 3D printing technology, and mechanical engineering design. Additionally, some projects and videos related are reviewed for further understanding. The schedule planning of the project is carried out to ensure the attainment of goals.

Once the concepts are studied understood, the schedule proceeds to the conceptual design of the automated token assembly system. During the second week to the fifth week, the design drafts were modified and improved multiple times. Meanwhile, the literature study on relevant topics is still ongoing to establish an understanding of the particular topics.

3D modeling is the core activity of the entire project. It requires the longest duration as this is the stage that detailed drawing, design revision, design optimisation, and design validation are conducted. Some of the parts are 3D printed, and hence evaluation can be established with the prototype. Then, 2D machining drawings are generated.

Next, the progress flow and tasks executed of the project are summed up and reported. In brief, the project progress can be planned and monitored from time to time with the aid of a flow chart and Gantt chart. The tasks should be completed ahead of time in order to avoid unforeseen circumstances that will delay the schedule.

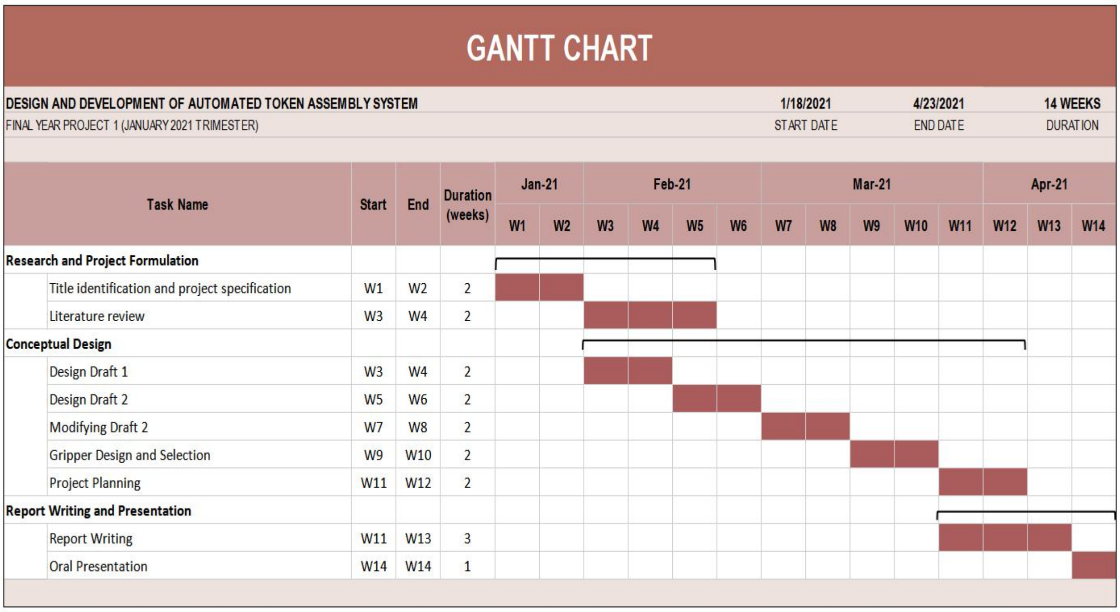


Figure 3.4: Project Gantt Chart (FYP 1)

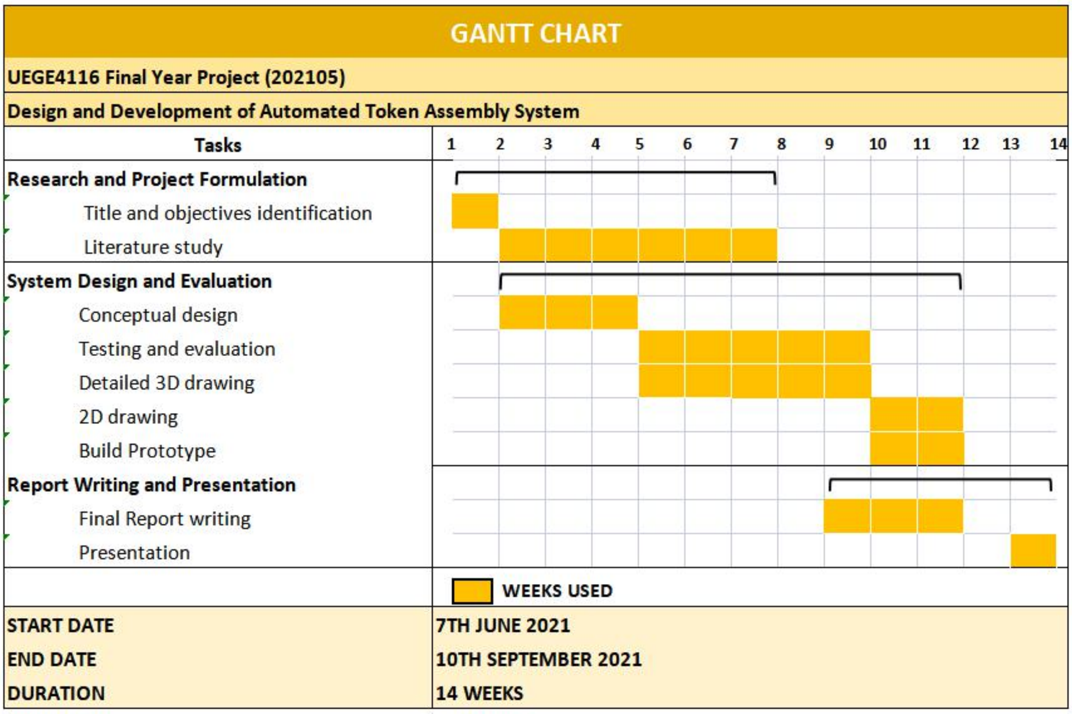


Figure 3.5: Project Gantt Chart (FYP 2)

3.2 Mechanical Engineering Design Overview

Defining the system requirements or specifications is the preliminary step of mechanical engineering design. It helps to attain the project goals with the desired conceptual design. Meanwhile, past projects on automated assembly machines are researched to explore the possibilities. The activities and tasks to be executed are well planned to ensure the smoothness of the project. The design is then optimise and validate to achieve the superior performance of the system.

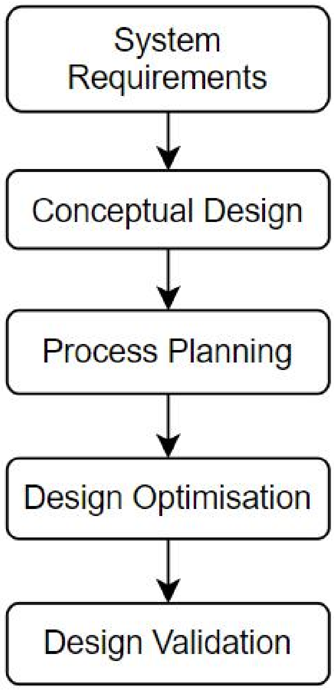


Figure 3.6: Mechanical Engineering Design Flow Chart

3.3 3D Printing Process Flow Chart

3D printing is chosen as the main manufacturing method to produce the prototype of the project. This technology is also known as additive manufacturing (AM), it uses successive layers of filaments to create a 3D product. The process steps of this manufacturing process are illustrated in Figure 3.7. Firstly, a 3D model is created using a 3D modeling software, Solidworks after the conceptual design is finalised. The CAD model is converted and saved as the STL file. The machining G-code is then generated by using software, Cura. Next, the machine is set up with the desired printing parameters. The model is built layer by layer. Last but not least, the printed product will undergo post-processing such as cleaning and polishing. The printed product will be used to evaluate the feasibility of the design.

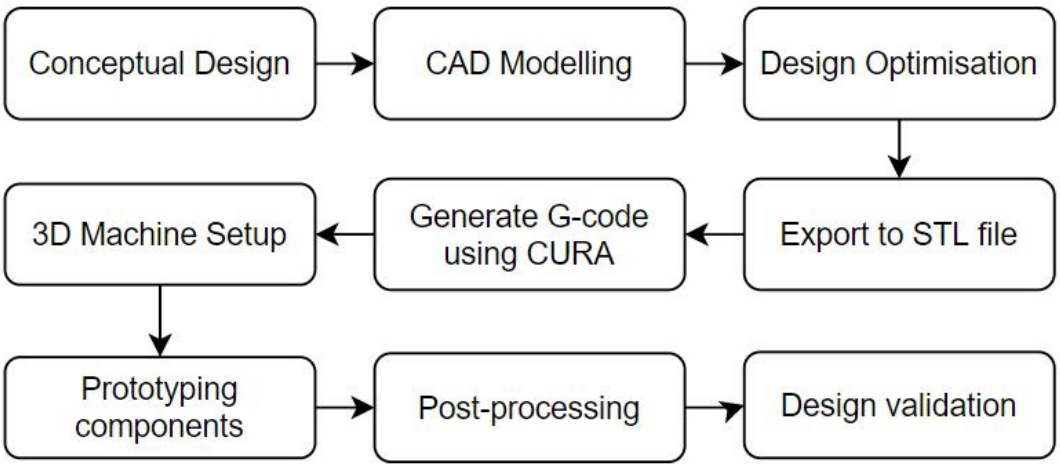


Figure 3.7: Engineering Design Flow Chart

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Door Gift Design

The door gift is named as "Hexolon", where the design is inspired by the logo of Tech Dome Penang. It served as physical evidence of visitors' journey to Tech Dome Penang. Hexolon is made up of 4 components, which includes three identical bodies to form a hexagon shape and a key to hold the three body parts together. The technical drawing of the door gift, Hexolon are shown in Figure 4.2.

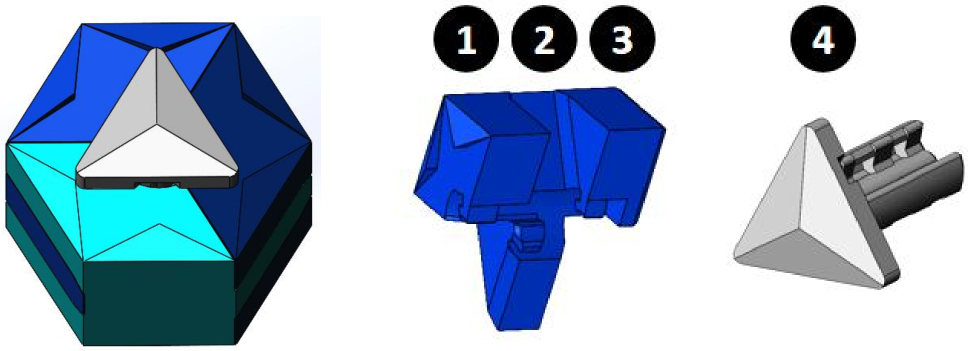


Figure 4.1: Door Gift (Hexolon)

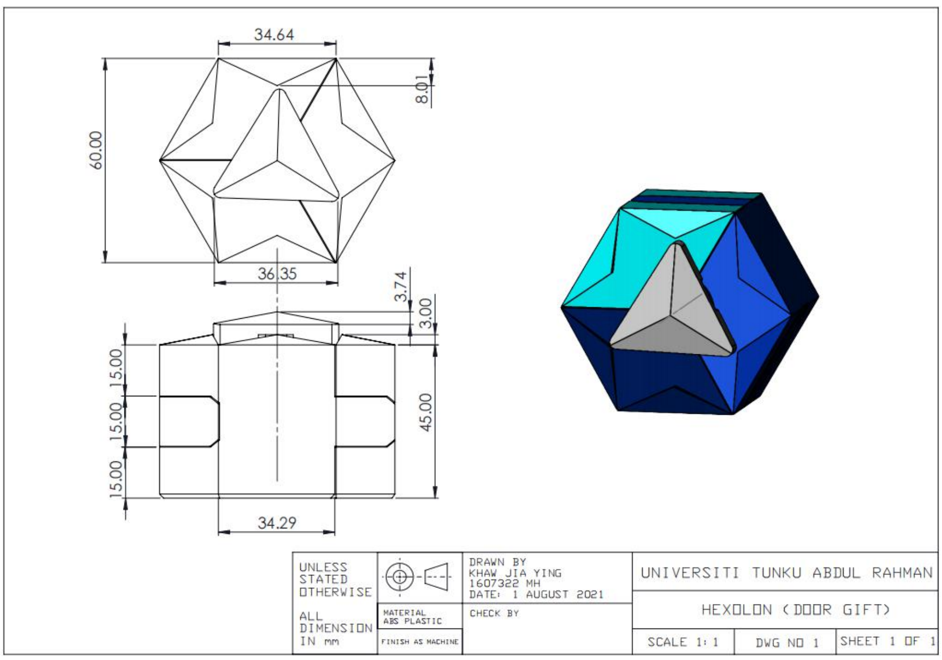


Figure 4.2: Technical Drawing of Door Gift (Hexolon)

4.1.1 Assembly Steps

There are a total of four steps to assemble the product. The first two steps involve assembling the three body components in forming a hexagon shape. Consequently, the key will be inserted into the keyhole. Lastly, the key should be rotated at 30 in the clockwise direction. The complete assembly steps of the product are presented in Figure 4.3.

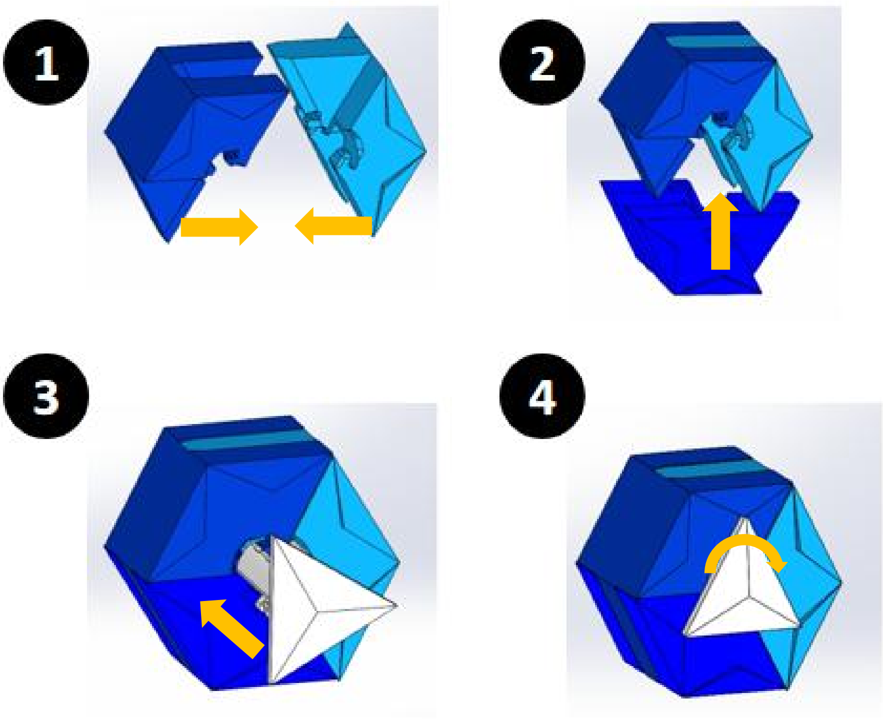


Figure 4.3: Assembly Steps of Hexolon

4.1.2 Estimated Cost

Table 4.1: Estimated Cost for 3D Printing Service of Door Gift (ABS)

No.	Components	Total Volume (mm^3)	Estimated Weight (gram)	Material used	Price (RM/ per gram)	Total Price (RM)
1	Body	163674	20g	ABS	0.40	8
2			20g			8
3			20g			8
4	Key		10g			4
					Total:	28

Table 4.2: Estimated Cost for 3D Printing Service of Door Gift (PLA)

No.	Components	Total Volume	Estimated Weight (gram)	Material used	Price (RM/ per gram)	Total Price (RM)
1	Body	163674	20g	PLA	0.20	4
2			20g			4
3			20g			4
4	Key		10g			2
					Total	14

The estimated cost to 3D print the door gift by using Acrylonitrile Butadiene Styrene (ABS) plastic and Polylactic acid (PLA) plastic are tabulated in Table 4.1 and Table 4.2.

Total volume = Length × Width × Height

= Total volume of rectangle - total volume of triangle

= (69.28 × 60 × 45) mm − (30 × 17.32 × 45) mm

=163674 mm^3

4.2 Automated Assembly System

This assembly machine is designed to facilitate a lesser number of assembly steps with a compact design. Elements such as ease of maintenance, ease of use, cost, and reliability were considered during the design thinking process. Several other methods of assembly have been considered during the brainstorming of this assembly machine design. The initial approach uses the station-station method where each step of the assembly is assembled according to each station before being transported to another station. This station involves more sensors to ensure accuracy and precision during the transport of the parts. More sensors contribute to more entities of failure and program complexity.

Suggestions for the actuators include pneumatic and electronic actuators linear actuators. Pneumatic actuators were not chosen for the main reason of the noise generated by the compressor used to actuate the system. To maintain consistent air pressure and volume for the system to function, the piston has to be triggered consistently and frequently at the compressor thus causing significant noise. Further complications of speed adjustments and air leakage further contribute to the reason to avoid the use of this system. Electronic actuators provide great torque and speed control. Besides, the approach to design the lightweight machine can be achieved. Due to the high cost of the actuators, this selection was omitted in comparison with the aluminum profile-based linear actuator. The average cost of the electronic actuator is RM 140 as compared to the aluminum profile-based linear actuator which only costs RM100 capped at a maximum. Furthermore, there is a standard length for the electronic linear actuator as compared to the other system which could be flexible according to the length required for this system.

Methods including Bowden tube mechanism and compliant mechanism were also considered in the process of deciding the gripper mechanism method. Bowden tube involves translating linear motion to a flexible degree of motion through the use of flexible or semi-flexible rods through a flexible tube. The flexibility of the mechanism is a strong benefit of machine designs with a setback of force lost during motion translation. It is found that some forces are lost to friction forces from the rod and the inner walls of the tube. The complexity of mounting the tubes in places further complicates the setup of the machine. A compliant mechanism is a flexible mechanism of transmitting different directions of forces through an elastic body deformation. With the use of a compliant mechanism, less part count and a more compact design could be achieved. In order for a compliant mechanism to be applied, material uniformity is crucial which is also a weakness of FDM 3D printing. A FDM 3D printer functions by printing a molten plastic layer on top of a cured printed layer. When the molten layer is layered on top, impurities and temperature differences caused the join between layers to be weaker. This is known as layer adhesion strength. Due to these factors, a compact and complex compliant mechanism could only be achieved through plastic injection which would be costly. With all the considerations and alternatives from above, the current system with the use of a magnet is chosen with the comparison of cost, reliability, and complexity.

Alternatives of transferring the parts from stations for assembly were the use of a conveyor system. Space is required for the conveyor system to operate. Most of the conveyor system occupies lateral space rather than vertical space which makes the assembly system bulky. Moreover, the cost of a conveyor system is more expensive as compared to a gravity-fed mechanism due to the number of components required for the system. Hence, a better option of implementing a gravity-fed system is chosen as the implemented design.

4.2.1 System Overview

The automated assembly system is made up of three body magazines, a key magazine, linear actuators, a gripper, and a main assembly acrylic board. Aluminum profiles are implemented as the machine frame due to their extraordinary flexibility and structural strength. The automated assembly machine is enclosed by the panels for safety purposes. This system can assembly ten door gifts in one cycle. The main components of this machine are tabulated in Table 4.3.

There are a total of seven stepper motors applied to the system. Three of them locate at the three linear actuators for body magazines, three locate at the x, y, and z-axis of movement of the gripper, and the remaining one locates at the linear actuator for key magazines. Each motor consists of one infrared sensor. Additional four infrared sensors will be mount on each magazine to get the users informed when the magazines are run out of components.

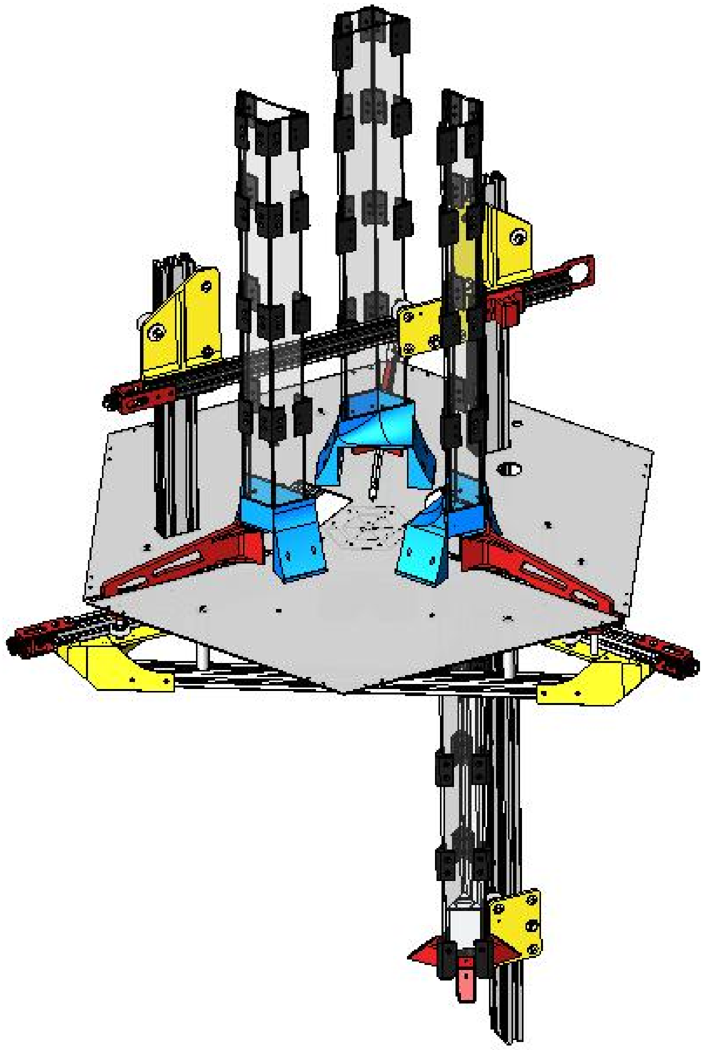


Figure 4.4: 3D Modeling of Automated Assembly System

Table 4.3: Main Components of Automated Assembly System

Part No.	Main Components	Quantity
a	Body magazines	3
b	Key magazine	1
c	Linear actuators for body magazines	3
d	Linear actuator for key magazine	1
e	Gripper	1
f	Main assembly table (acrylic)	1
g	Stepper motors	7
h	Infrared sensors	11

4.3 Assembly Methods

The assembly components are separated into two parts, namely 'Body' and 'Key'. Each key magazine and body magazine is loaded with 10 components. The initial step to assemble the door gift is to ensure the actuators are back to their original position as shown in Figure 4.5.

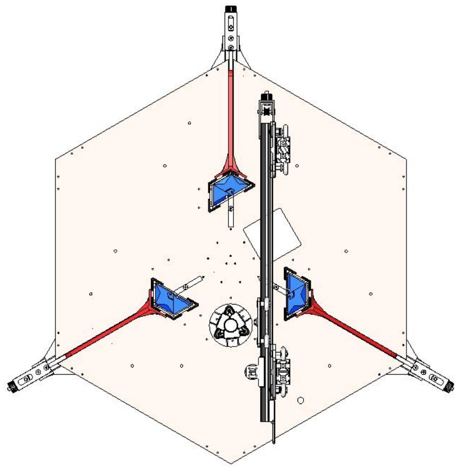


Figure 4.5: All Actuators back to Original Position

The 'Body' is first assembled from 3 sides of a triangular point towards the centroid, then the key is inserted from the top and rotated 30 degrees to lock and hold the bodies together. A linear actuator is used to push the support arm which holds one unit of the body. When the bodies are assembled and locked together by the key, one of the actuators proceeds to push the assembled component out from the centroid, also known as the assembly zone.

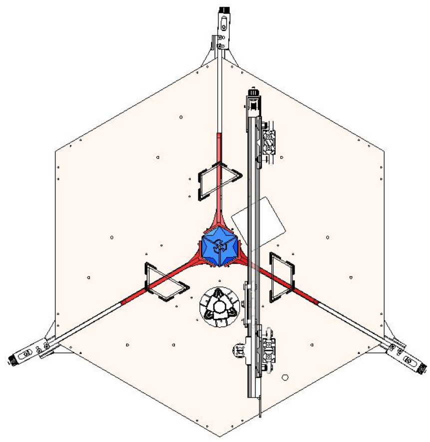


Figure 4.6: Body Components Assembly

The two actuators are set to return to the original position to prevent a collision. Meanwhile, the key component will be grasp from the retainer lid and assemble into the body components. The gripper will be twisted to rotate the key.

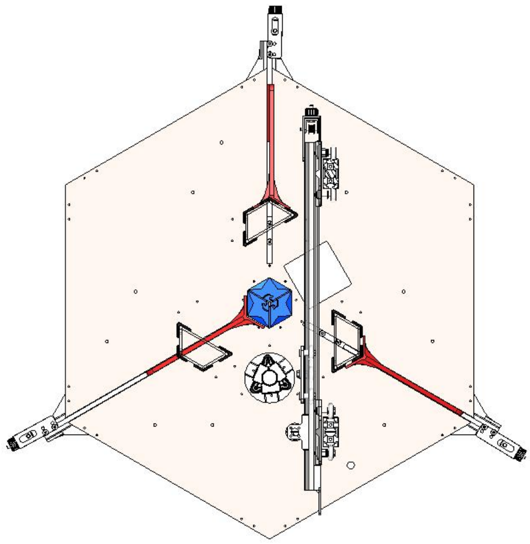


Figure 4.7: Two Actuators back to Original Position

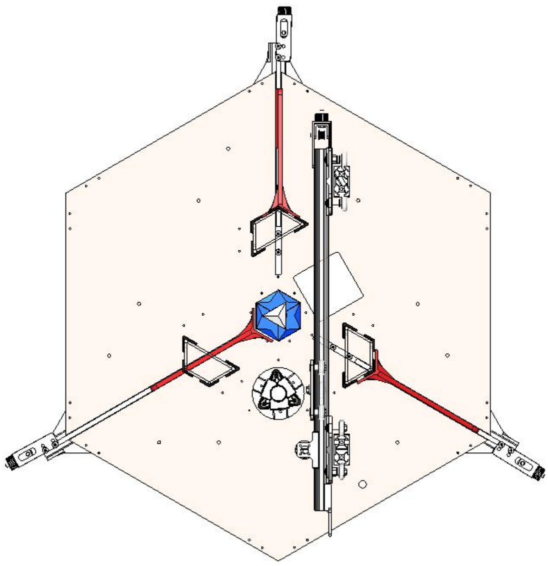


Figure 4.8: Assembled Door Gift

Last but not least, the assembled door gift with be pushed by the remaining stayed actuators to the output zone on the assembly table. The actuators will get back to its original position again for next assembly.

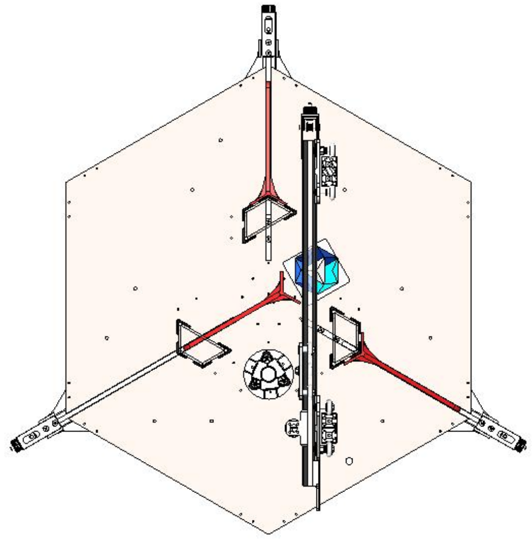


Figure 4.9: Push Assembled Door Gift to Output Zone

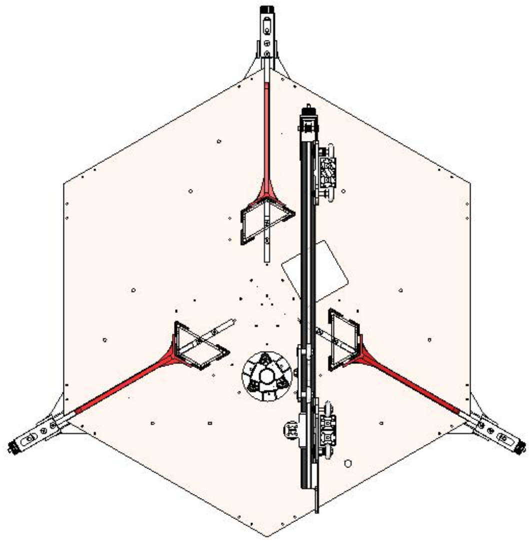


Figure 4.10: All Actuators back to Original Position

4.4 Key Magazine Assembly

To enhance the efficiency of loading and productivity, the magazine system is implemented to hold more parts in a single unit order. The magazine is able to hold up to ten keys. Figure 4.11 shows the complete assembly of a single key magazine. It is made up of three acrylic panels with l-brackets, a retainer lid, a key holder, and a key bed. Polycarbonate panels are chosen as it made out of carbon composite material which gives great impact strength. The clear polycarbonate panels allow technicians and machine operators to have a clear view of the part count. A linear actuator will be pushing the key from the bottom of magazines, and the acrylic panels will act as the guide for the key to move in linear motion.

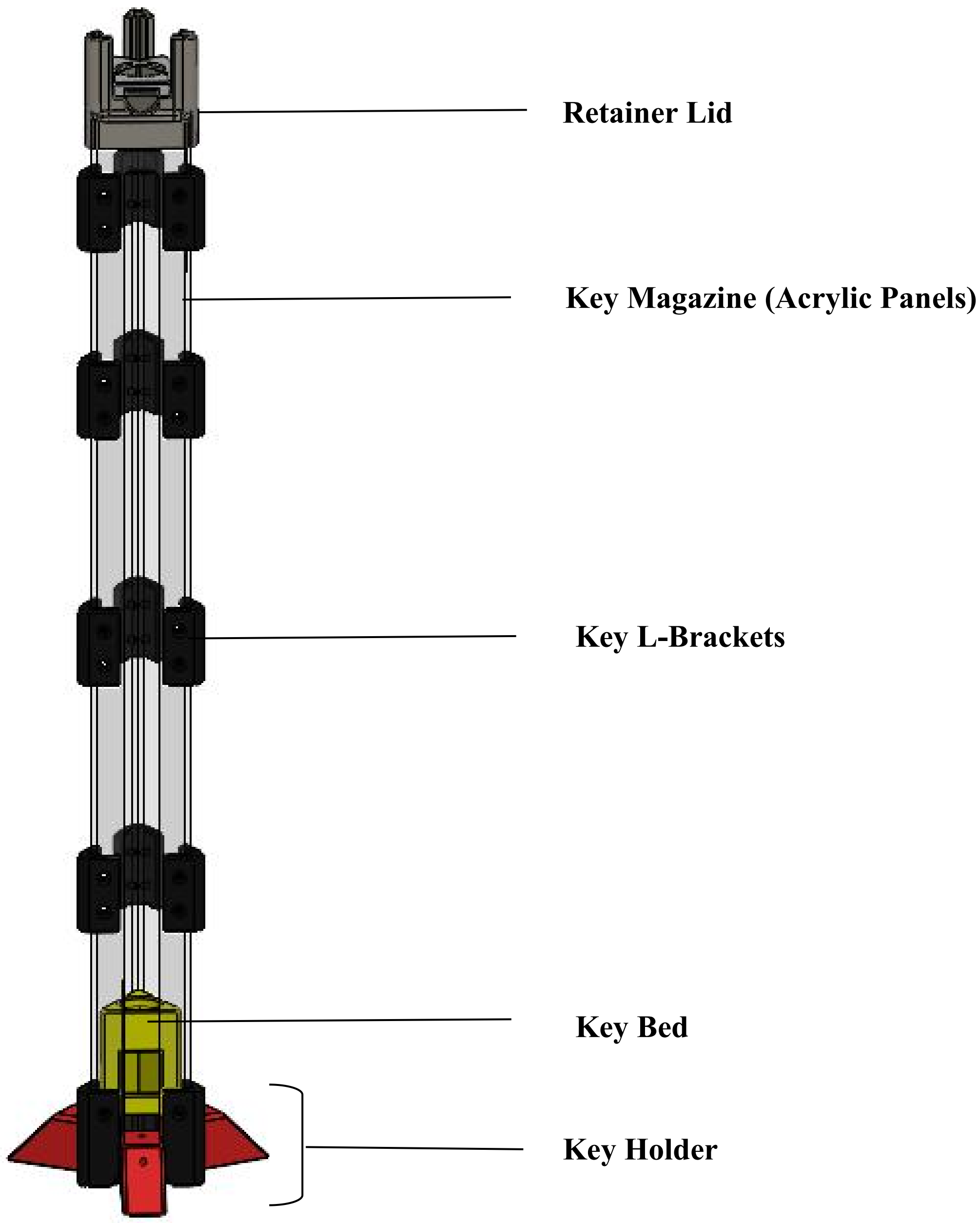
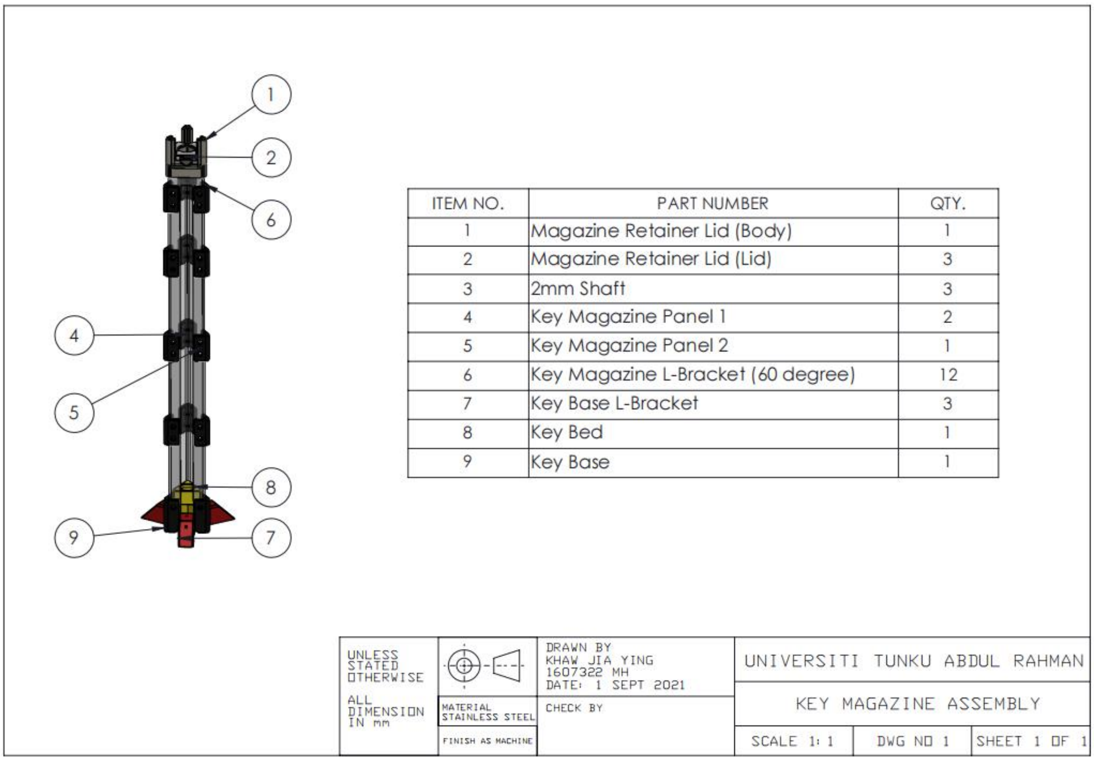


Figure 4.11: Key Magazine



ITEM NO.	PART NUMBER	QTY.
1	Magazine Retainer Lid (Body)	1
2	Magazine Retainer Lid (Lid)	3
3	2mm Shaft	3
4	Key Magazine Panel 1	2
5	Key Magazine Panel 2	1
6	Key Magazine L-Bracket (60 degree)	12
7	Key Base L-Bracket	3
8	Key Bed	1
9	Key Base	1

Figure 4.12: B.O.M List of Key Magazine

4.4.1 L-Brackets

There are a total of twelve l-brackets for each key magazine assembly. The function of these l-brackets is to join the magazine panels together. Unlike the normal 90 degrees l-bracket, these l-brackets are specially designed with an angle of 60 degrees to hold the triangle key components firmly.

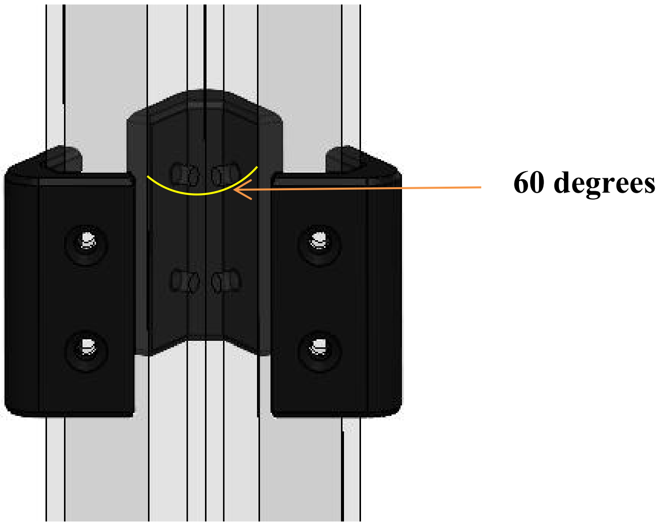


Figure 4.13: Key Magazine L-Brackets

4.4.2 Retainer Lid

The retainer lid as shown in Figure 4.14 serves the purpose of holding the key components before the gripper grasps it. As mentioned earlier, the key components will be transferred from the bottom of the magazines. Hence, the retainer consists of three gravity-fed lids that can hold the key upright. When the key is pushed until the maximum limit, the actuator will move slightly backward and hence the key can firmly drop on the lids. The motion of the retainer lid is shown in Figure 4.15. Besides that, the retainer design comprises compliant clips that can be attached to the key magazines. It reduces the workload to remove and unscrewing the retainer lid from the magazines.

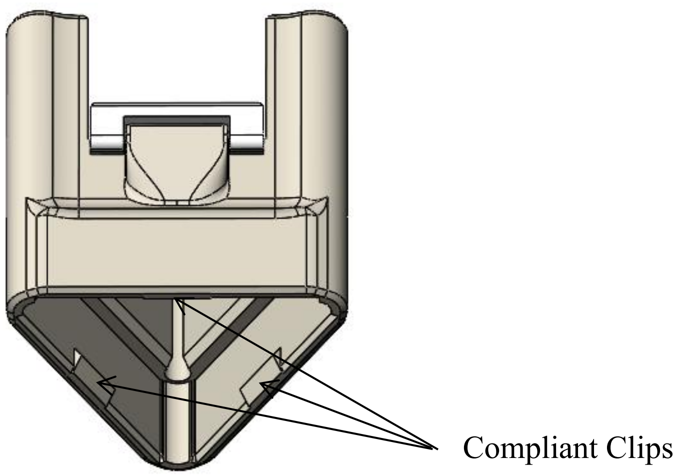


Figure 4.14: Retainer Lid

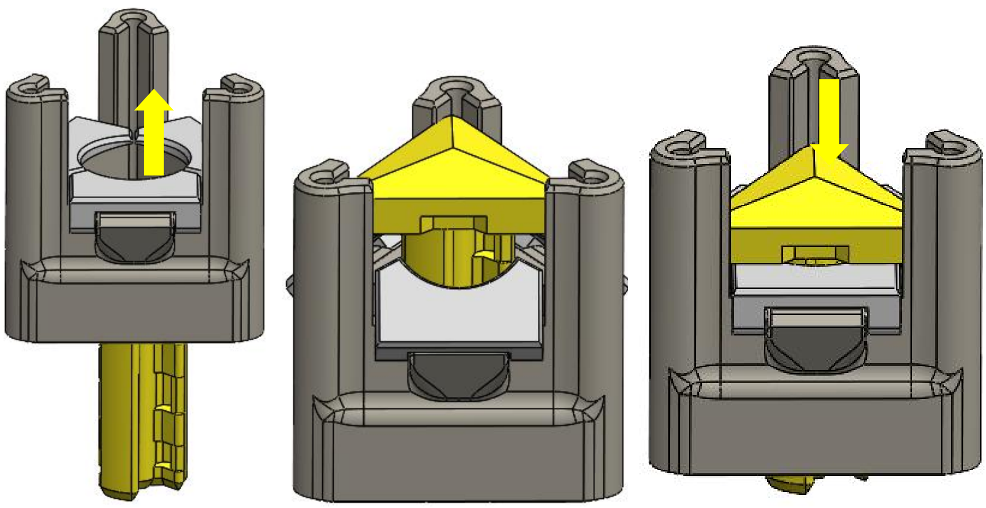


Figure 4.15: Motion of Retainer Lid

4.4.3 Key Magazine's Base and Holder

The key magazine's base and holder are designed to hold and stable the magazines. It is made up of a customized base and three 90 degrees l-brackets.

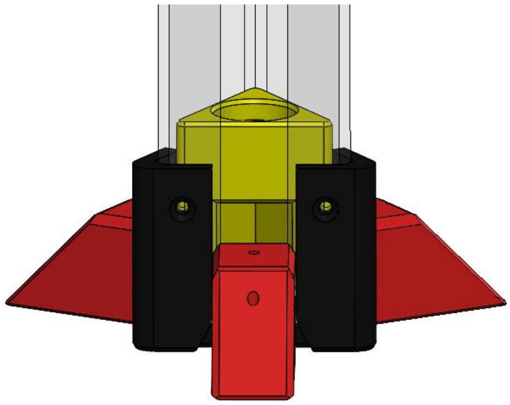
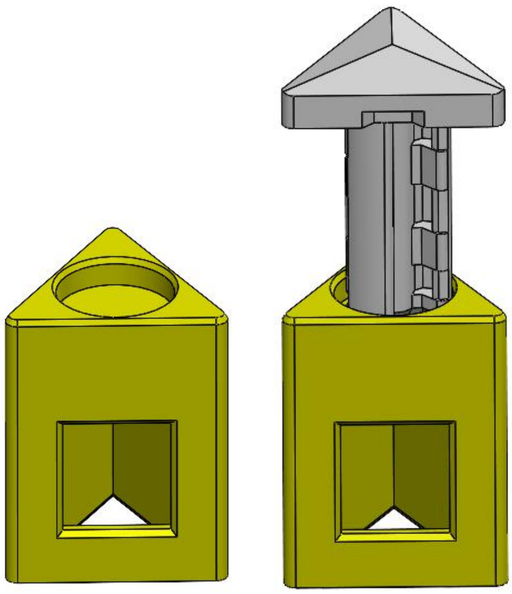


Figure 4.16: Key Base and Holder

4.4.4 Key Bed

The key bed was designed to act as a bed to hold and align the key in the right position. It prevents the key from shivering when moving inside the magazines. The shell hole is designed to fit the actuator for linear actuation.



(a) (b)

Figure 4.17: Key Bed (a) without key, (b) with key

4.5 Linear Actuator of Key Magazine

V-slot aluminum profile linear rail is chosen as the linear actuator setup for this assembly machine. The setup is broken down into two sub-assemblies which are the belt-driven rail unit and a customized support arm. The belt-driven rail unit consists of one NEMA 17 stepper motor, one idle 12 tooth GT-2 sheave, one 12 teeth set crew hub GT-2 sheave, rail arm mount, motor mount, and 2020 aluminum profile.

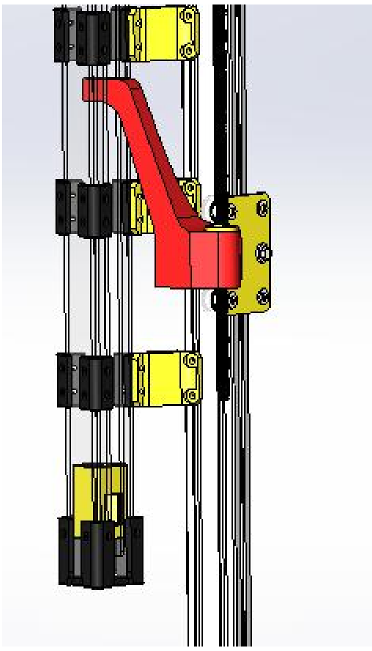


Figure 4.18: Key Bed (a) without key, (b) with key

4.6 Body Magazine Assembly

The body magazine is gravity fed, built together with polycarbonate panels held together by ABS printed joints. Figure 4.19 shows a prototype sketch of the proposed magazine system. The body magazine is made up of sixteen l-brackets, three acrylic panels and a magazine holder. Each magazine is able to hold ten body components of the door gift. Polycarbonate panels are chosen as it made out of carbon composite material which gives great impact strength. The clear polycarbonate panels allow technicians and machine operators to have a clear view of the part count.

At the bottom of the magazine holder, two opposite sides of the polycarbonate panels are cut away to allow the support arm from the linear actuator system to push the part towards the assembly zone, away from the magazine. While the support arm pushes through the magazine, the stem of the arm holds the second part on top in position inside the magazine. As the arm travels backward and away from the magazine, the second part falls into place getting ready for the next actuation. The magazines could be detached from the magazine mount when needed.

Once the magazine has been emptied, a new part-filled magazine could be replaced with a short period of time. This design is a direct reference to Nerf Rival, a pump-action toy gun by toy manufacturing company 'Hasbro'.

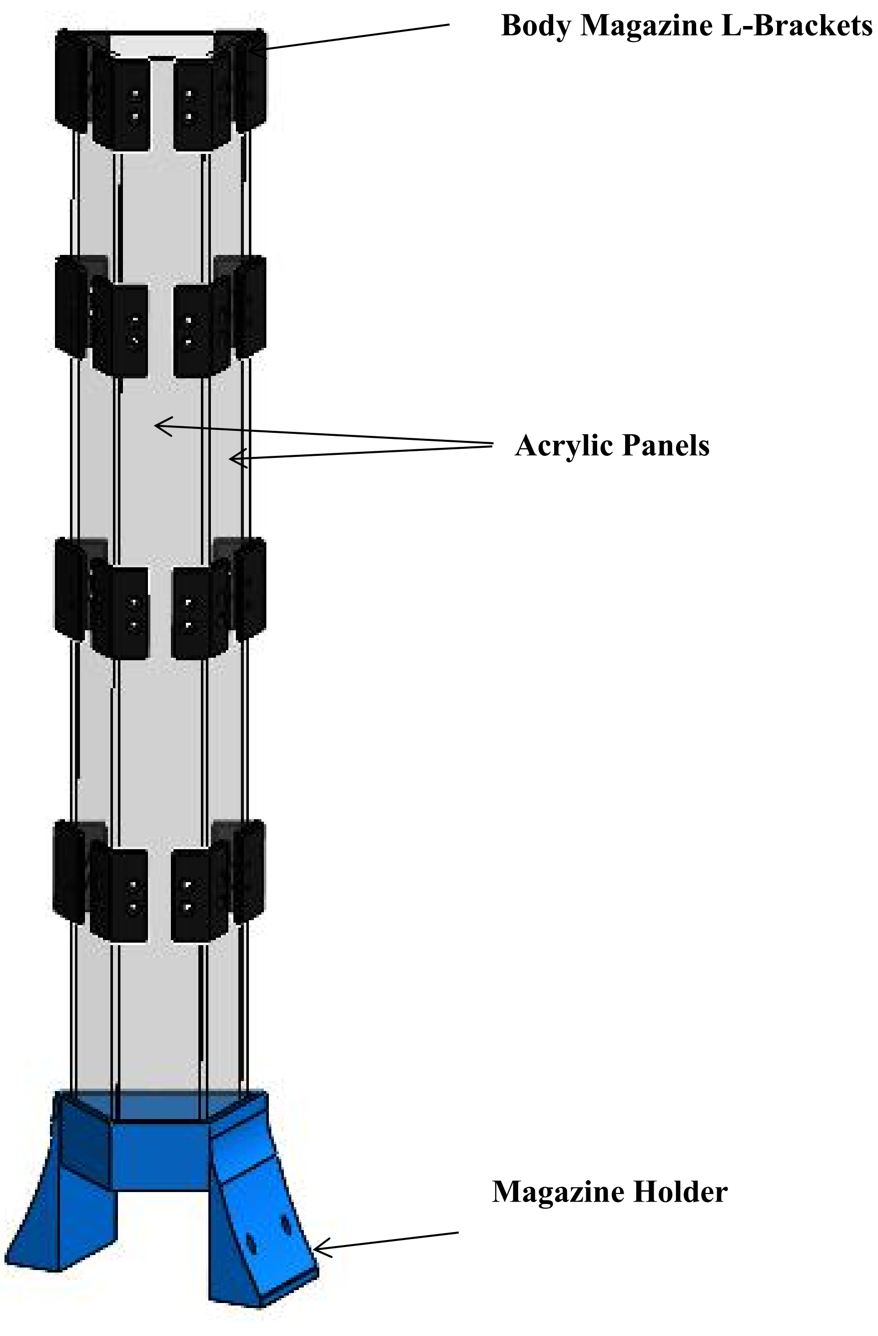


Figure 4.19: Body Magazine Holder

4.6.1 Body Magazine's Holder

The holder is designed to hold the magazines together and mount them on the assembly table. The initial design of the holder was relatively bulky and complex, hence the optimised design was presented in Figure 4.20.

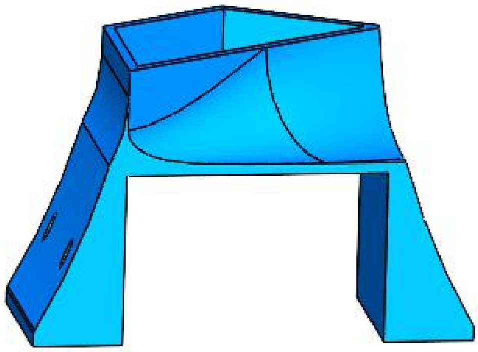
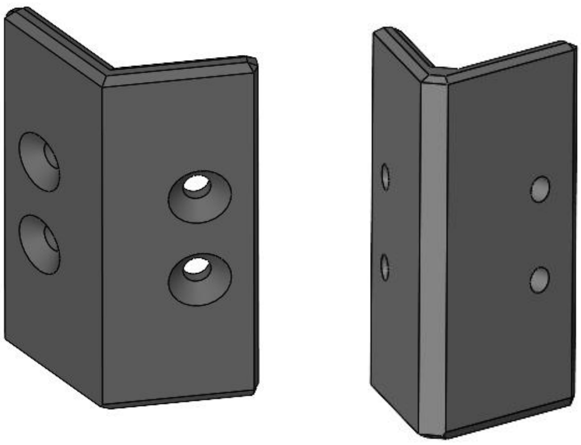


Figure 4.20: Body Magazine Holder without Drum System

4.6.2 L-Brackets

The l-brackets of the body magazines serve the same function as the l-brackets of the key magazines. However, two different angle brackets, 60 degrees and 120 degrees, were used to hold the panels of the body magazine.



(a) (b)

Figure 4.21: Magazine L-Brackets: (a) 120 degrees and (b) 60 degrees

4.7 Gripper

The gripper is mainly responsible for lifting the key and locking it to the assembled body. This gripper consists of two parts which are the main body and the clip. A semi-complex translation of motion is integrated into this gripper system where magnets are used to further enhance the motion accuracy and gripping strength. An embossed gripping slot is designed on the key for the gripper's clip to attach. The clipper has two modes, which are the gripping mode and release mode. At gripping mode, the clip rotates 20 degrees clockwise while it rotates 20 degrees counter-clockwise at release mode. When the key is inserted into the gripper, the top lever pushed by the key triggers the clip to gripping mode. The vertical movement of the key forces the clip to translate vertical motion to a rotary motion. An N38 neodymium magnet is embedded at the top portion of the clip. When the clipper rotates, the magnet further assists the travel towards the body with a magnetic point. Due to the slightly imbalanced nature of the magnetic strength, the tendency for the clipper to stay at mid-rotation is very unlikely, thus ensuring the consistency of mode transition. The strength of the gripper is affected by the distance of the magnet from the rotary axis of the clip. The formula for Moment of Force is derived as:

$$M \text{ (Moment)} = F \text{ (Force)} \times s \text{ (Displacement)} \quad (4.1)$$

The magnet in this system represents the force applied to the clip which also represents the lever. The further away the magnet is located from the axis, the larger the moment for the system, thus contributing to a larger clipping force. The magnet distance is designed to compensate enough force for the gripper to remove the key from the thermoformed tray while maintaining the maximal strength required to detach the assembled key from the gripper. To allow such a complex mechanism to be implemented with a minimal amount of parts, an additive manufacturing method is selected and to be 3D printed using ABS plastic.

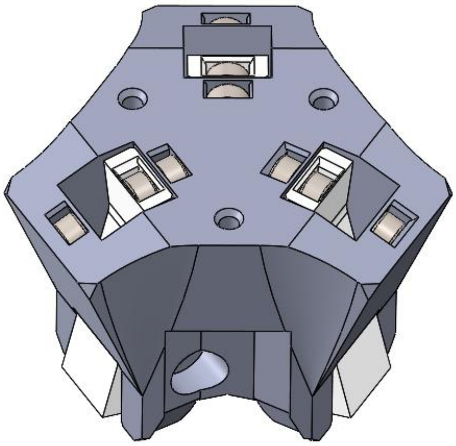


Figure 4.22: Isometric View of the Gripper

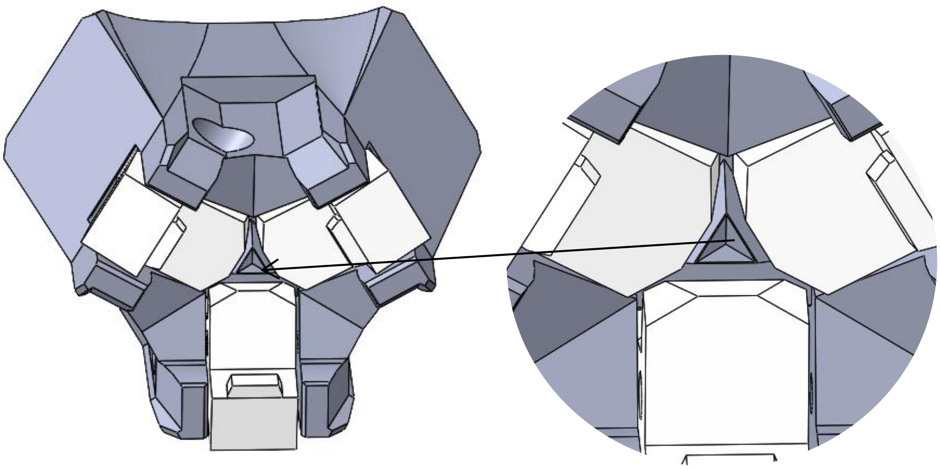


Figure 4.23: Bottom View of the Gripper

4.8 Linear Actuator Assembly of Body Magazines

V-slot aluminum profile linear rail is chosen as the linear actuator setup for this assembly machine. The setup is broken down into two sub-assemblies which are the belt-driven rail unit and the support arm. The belt-driven rail unit consists of one NEMA 17 stepper motor, one idle 12 tooth GT-2 sheave, one 12 teeth set crew hub GT-2 sheave, belt tensioner, motor mount, and 2020 aluminum profile. This sub-assembly serves the purpose of actuation through the conversion of rotary motion to linear motion.

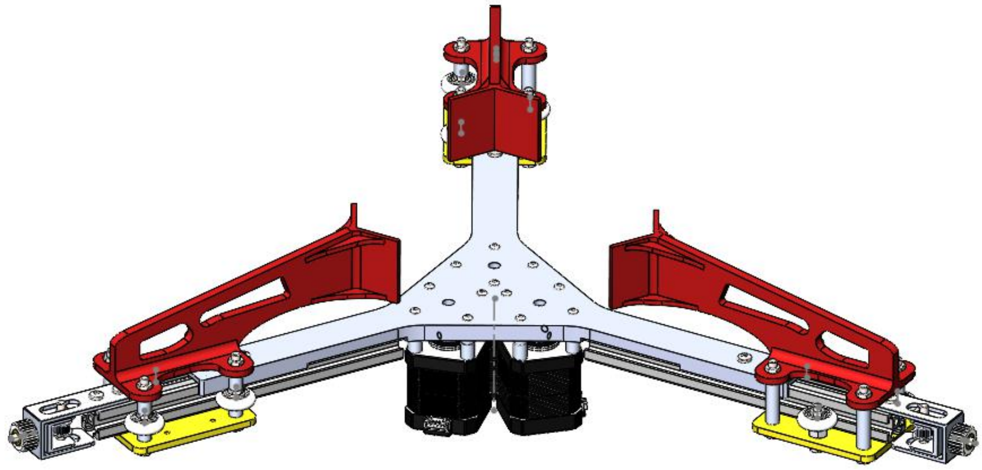


Figure 4.24: Linear Actuator Assembly of Body Magazines

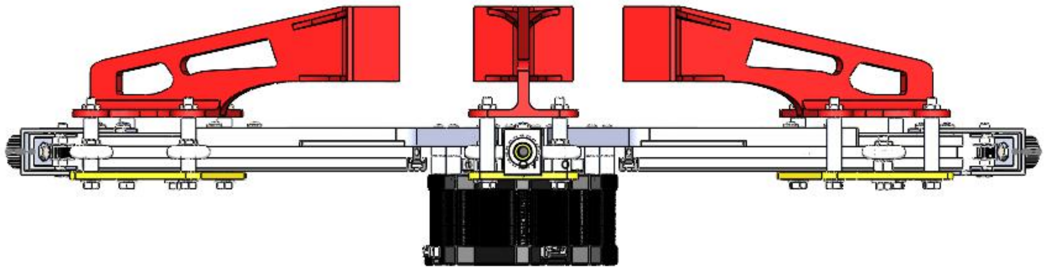


Figure 4.25: Linear Actuator Assembly of Body Magazines (Right View)

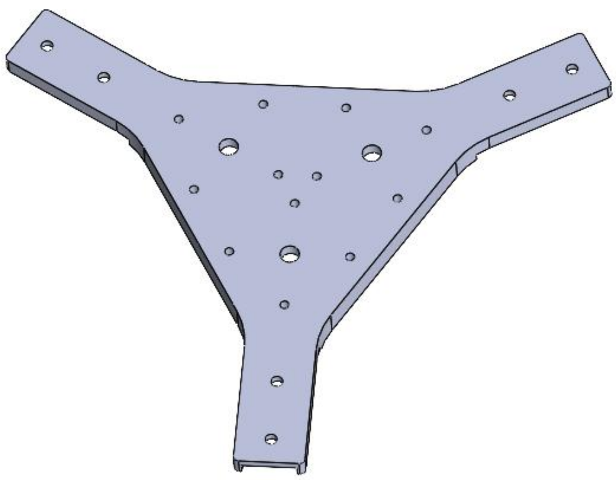


Figure 4.26: Aluminum Profile Center Joint

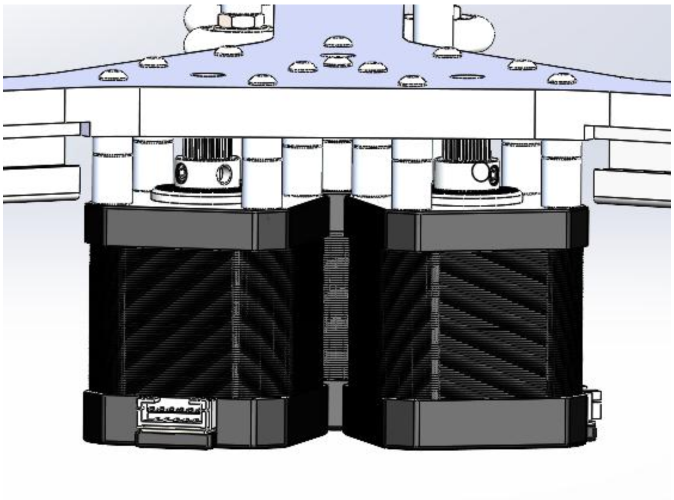
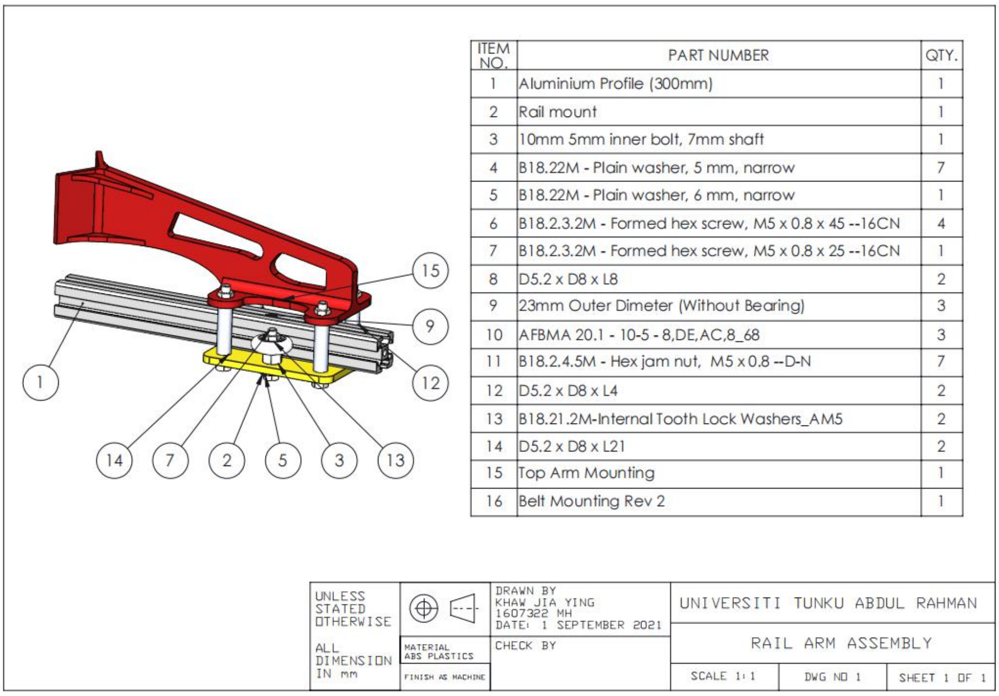


Figure 4.27: Nema 17 Stepper Motor

4.8.1 Support Arm Unit

The support arm unit comprises three nylon fitted bearings, one eccentric nut, one mounting plate, and one 3D printed ABS support arm. The support arm unit serves the purpose of mounting the support arm onto the rail system to enable free and smooth linear movement. The complete system is mainly actuated by a GT-2 belt driven with the stepper motor setup with micro-stepping to minimize slipping of steps. The stepper motor translates rotary motion to linear motion through the belt, moving the plate mounting the support arm. The belt is mount on the belt mounting as shown in Figure 4.31. The mounting arm is attached firmly by adjusting the grip depth of the bearing twisting the eccentric nut attached to the nylon fitted bearing.

Due to the offset of the hole in the eccentric nut, when it is rotated to a suitable angle it will offset the screw holding the bearing closer or further away from the groove of the aluminum profile. The eccentric nut provides further flexibility of tuning to compensate machining tolerances (illustrated in Figure 4.29). This system resembles the linear rail used in commercial desktop 3D printers and has been proven to be reliable, easy to calibrate with relatively minimal wear and tear.



ITEM NO.	PART NUMBER	QTY.
1	Aluminium Profile (300mm)	1
2	Rail mount	1
3	10mm 5mm inner bolt, 7mm shaft	1
4	B18.22M - Plain washer, 5 mm, narrow	7
5	B18.22M - Plain washer, 6 mm, narrow	1
6	B18.2.3.2M - Formed hex screw, M5 x 0.8 x 45 --16CN	4
7	B18.2.3.2M - Formed hex screw, M5 x 0.8 x 25 --16CN	1
8	D5.2 x D8 x L8	2
9	23mm Outer Dimeter (Without Bearing)	3
10	AFBMA 20.1 - 10-5 - 8,DE,AC,8_68	3
11	B18.2.4.5M - Hex jam nut, M5 x 0.8 --D-N	7
12	D5.2 x D8 x L4	2
13	B18.21.2M-Internal Tooth Lock Washers_AM5	2
14	D5.2 x D8 x L21	2
15	Top Arm Mounting	1
16	Belt Mounting Rev 2	1

Figure 4.28: B.O.M List of Rail Arm Assembly

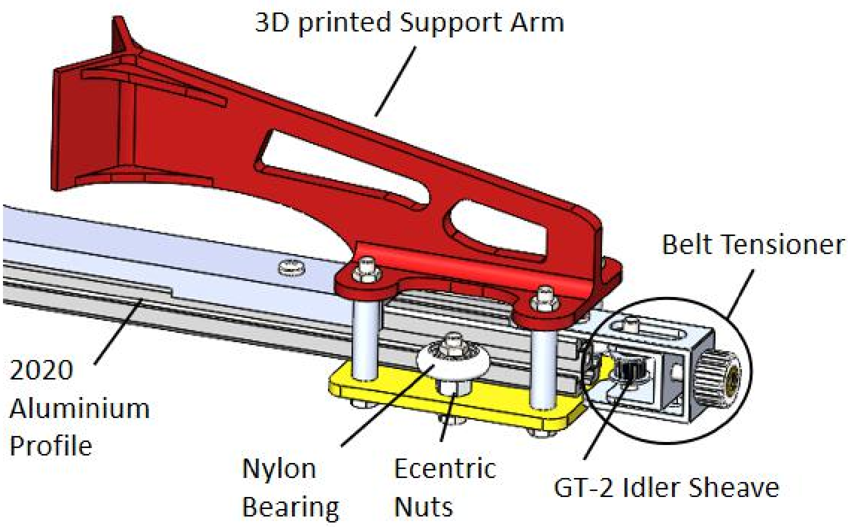


Figure 4.29: Support Arm Unit Assembly

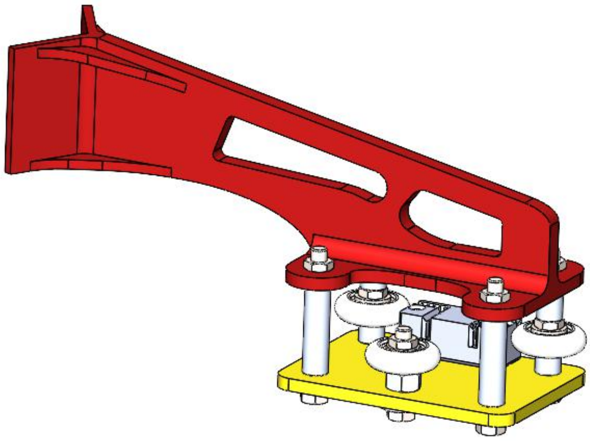


Figure 4.30: Support Arm Unit

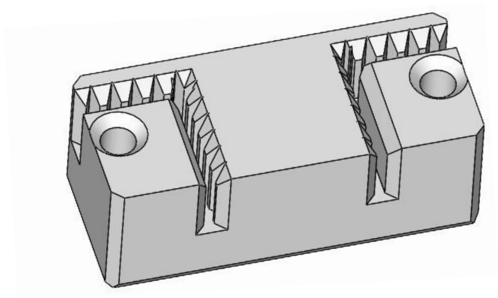


Figure 4.31: Belt Mounting

4.9 System Frames

Aluminum profiles are implemented as the machine frame due to their extraordinary flexibility and structural strength. The types of aluminum profiles used are 2020 and 2040.

4.9.1 Spar Joint

The spar joints were designed and 3D printed to mount and connect the joints of two aluminum profiles together. The joint for the gripper rail as shown in Figure 4.32 has customized design to fit the aluminum profile 2020 and 2040.

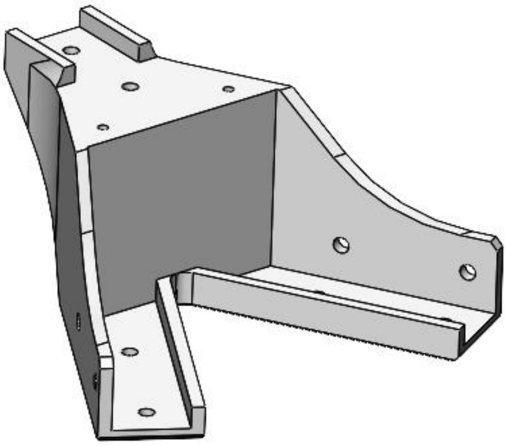


Figure 4.32: Spar Joint for Aluminium 2020

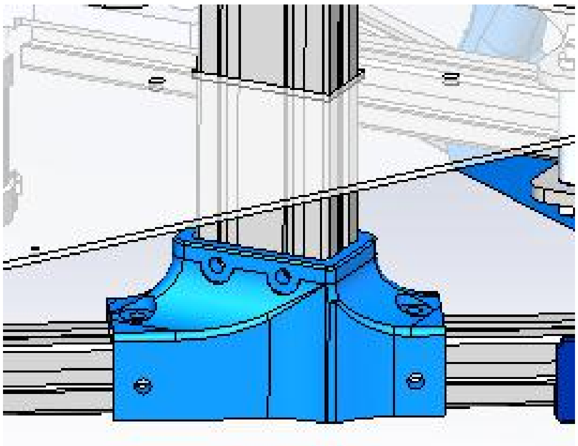


Figure 4.33: Spar Joint for Aluminum 2020 and Aluminium 2040

4.9.2 Table Support

Since there are some offsets between the assembly table and aluminum frames, the table supports are designed and mounted between both components to serve superior stability and structural strength.

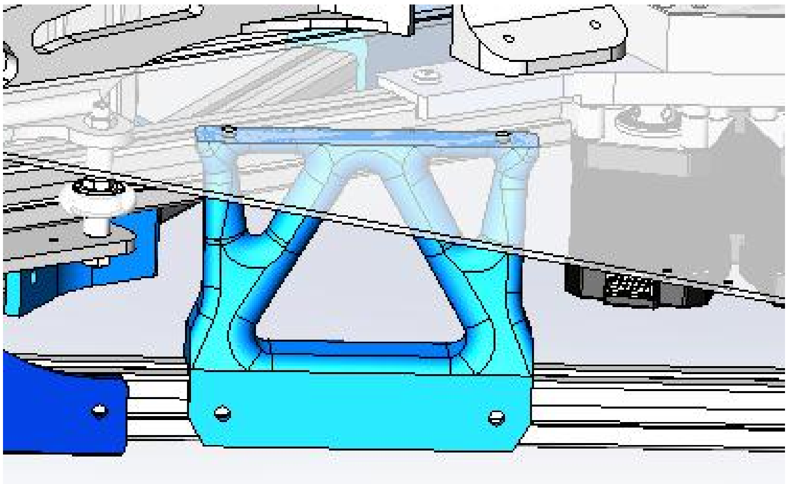


Figure 4.34: Table Support

4.10 Revolution of Sub-systems Design

Throughout the design validation process, some of the components were 3D printed and the design was optimised to achieve the highest performance. Hence, this subtopics reveals the design revision of the components with descriptions.

4.10.1 Key Magazine

Thermoformed key tray was proposed initially as it is one of the most economical manufacturing strategies. Apart from manufacturing cost, it contributes benefits to rapid prototyping development and adaptive to design requirements. However, this idea was deprecated after a series of attempts at process validation. The key tray was thermoformed by using the Polyethylene Terephthalate Glycol (PETG) plastics with the 3D printed molds. Although the percentage of the cavity was increased from 2.5 % to 5 %, yet the outcome of both attempts was still undesired. One of the main causes of the failure was due to the thermoforming machine does not support the pre-stretch function by blowing. Hence, irregular stretching of material resulted in the inconsistent dimensions of the product. The resulting problem also caused important dimensions with sharper edges to fail. Therefore, the final product of the thermoformed tray could not hold the 'key' component firmly. Further speculations are the unsuitable thickness of materials being used which may affect the product resolution needed.

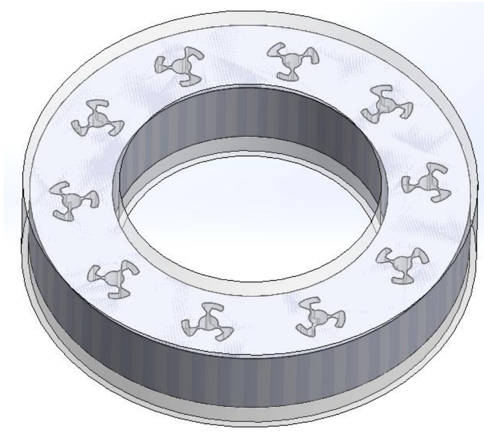


Figure 4.35: First Design Revision of Key Magazine

Figure 4.36: Thermoformed Key Tray with 5% of Cavity

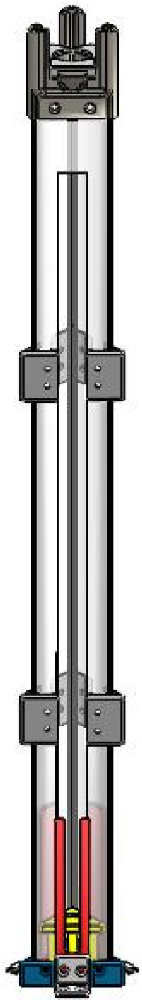
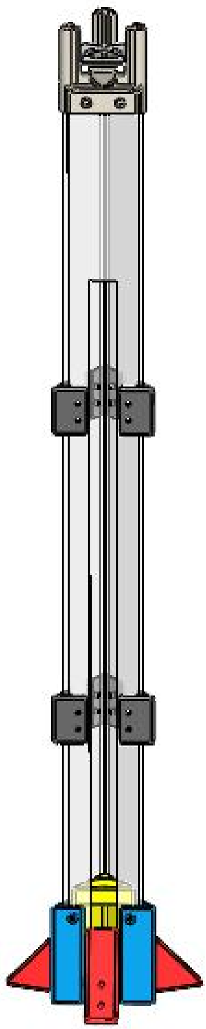
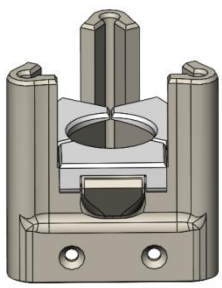
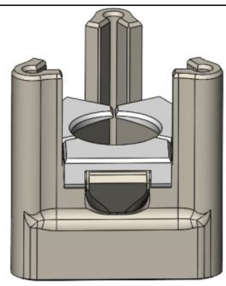
Figure 4.37: Thermoformed Key Tray

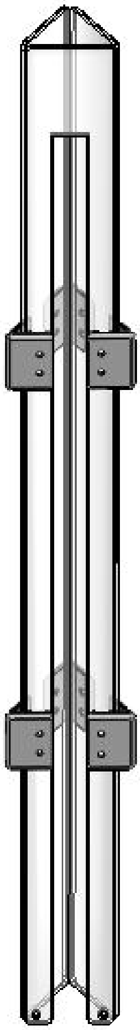
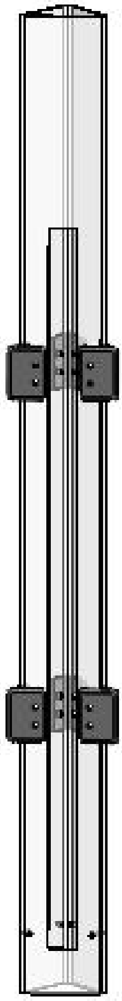
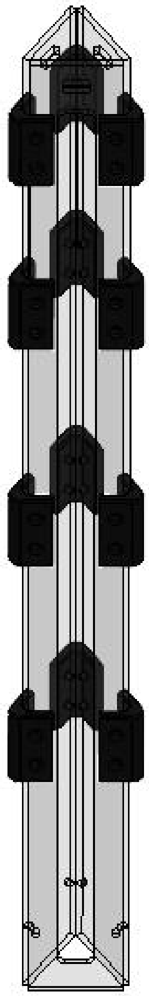
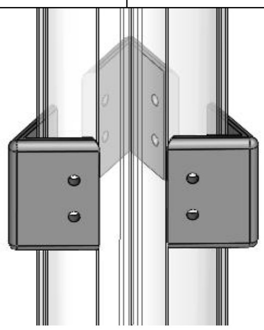
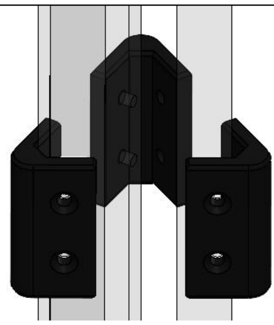
As a result, a magazine system that is able to hold more parts in a single unit order is implemented to reduce the reloading and cycle time. Figure 4.38 shows the 3D printed magazine of the new conceptual design. The design of the key magazine was revised several times to further improve the system performance.

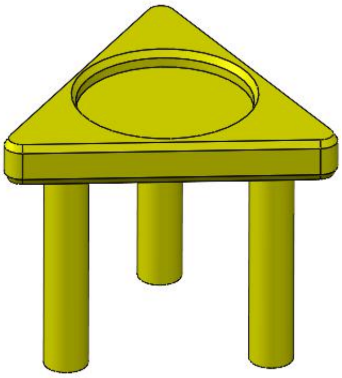
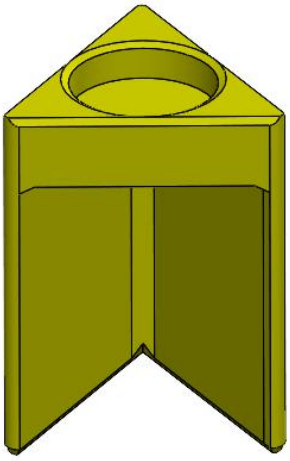
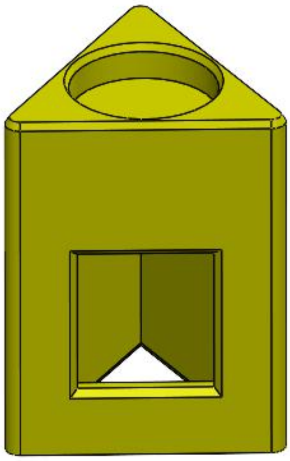
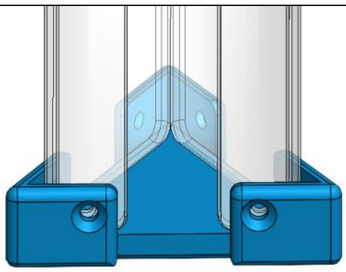
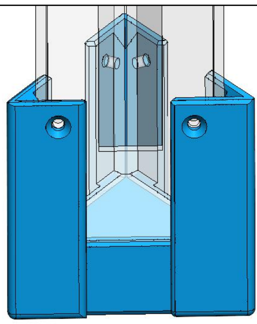
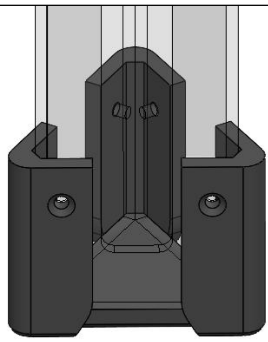
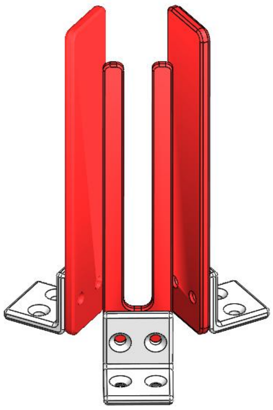
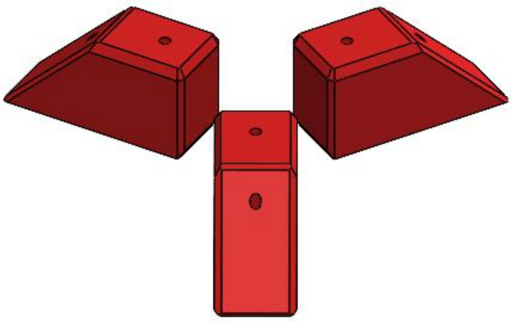
Figure 4.38: 3D Printed Key Magazines

In the second and third revisions, six l-brackets were used to mount the acrylic magazine panels together. However, it turned out that the keys inside the magazine are shivering during testing due to an insufficient amount of l-brackets. Hence, the l-brackets are increased to twelves to increase the stability of the acrylic magazines. Additional compliant clips were added to the final revised retainer lid design for the efficient loading and unloading process. The design key bed, key magazine base, and holders were modified to achieve better system performance. Apart from that, the initial design of the key drum was replaced by a hexagon shape. This is due to most of the FDM printers work effectively on straight lines with their XYZ coordinate system compared to circles. Improper calibration of the X and Y axis could lead to an imperfect round shape. The 3D models of each design revision of the key magazine are illustrated in Table 4.4.

Table 4.4: Design Revision of Key Magazine Assembly

<table>
<tr><th></th><th>Revision 2</th><th>Revision 3</th><th>Final Design</th></tr>
<tr><td>Assembly</td><td>
Figure 4.39: Key Magazine Assembly Revision 1</td><td>
Figure 4.40: Key Magazine Assembly Revision 2</td><td>
Figure 4.41: Final Revision of Key Magazine Assembly</td></tr>
<tr><td>Retainer</td><td colspan="2">
Figure 4.42: Retainer Lid Assembly Revision 1</td><td>
Figure 4.43: Final Revision of Retainer Lid Assembly</td></tr>
</table>

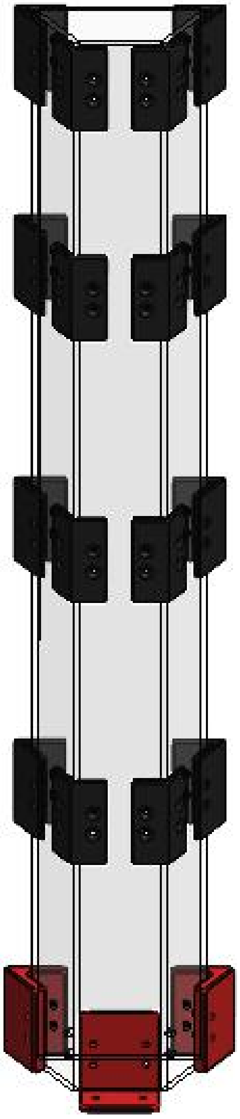
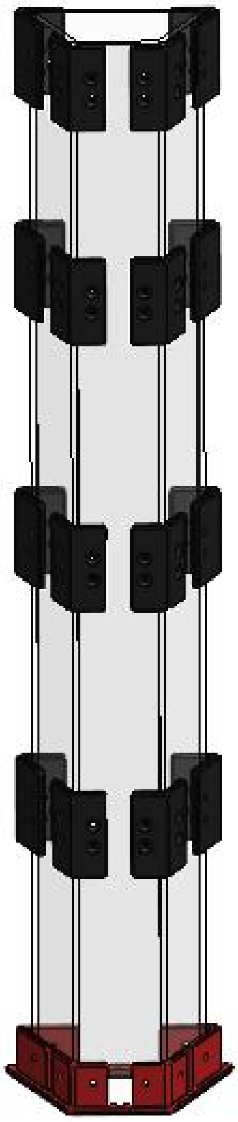
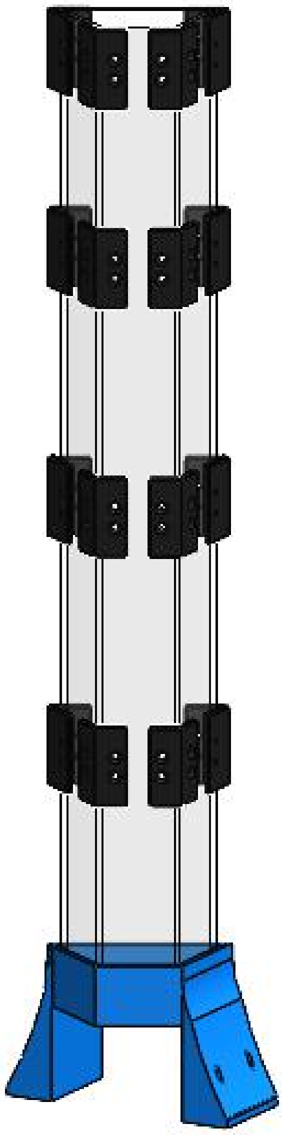
Magazine	 Figure 4.44: Key Magazine Revision 1	 Figure 4.45: Key Magazine Revision 2	 Figure 4.46: Final Revision of Key Magazine
Brackets	 Figure 4.47: Key L-Brackets Revision 1		 Figure 4.48: Final Revision of Key L-Brackets

Key bed	 Figure 4.49: Key Bed Revision 1	 Figure 4.50: Key Bed Revision 2	 Figure 4.51: Final Revision of Key Bed
Magazine's base	 Figure 4.52: Key Base Revision 1	 Figure 4.53: Key Base Revision 2	 Figure 4.54: Final Revision of Key Base
Key magazine's holders	 Figure 4.55: Key Holder Revision 1	 Figure 4.56: Final Revision of Key Holder	

4.10.2 Body Magazine

Similar to the key magazine, the design of the gravity-fed body magazine was improvised several iterations to achieve better stability and efficiency.

Table 4.5: Design Revision of Key Magazine Assembly

	Revision 1	Revision 2	Final Revision
Assembly	 Figure 4.57: Body Magazine Assembly Revision 1	 Figure 4.58: Body Magazine Assembly Revision 2	 Figure 4.59: Final Revision of Body Magazine Assembly

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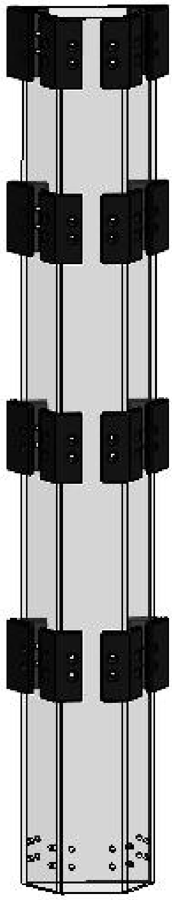
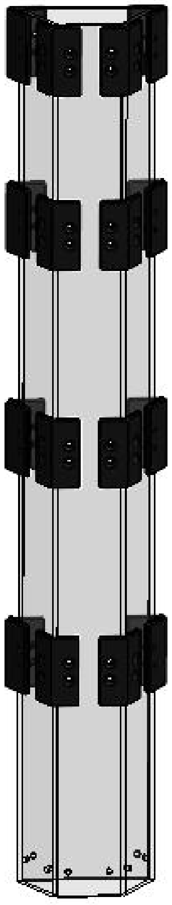
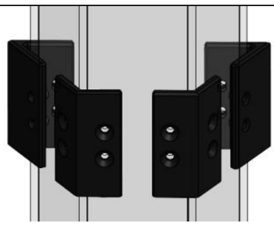
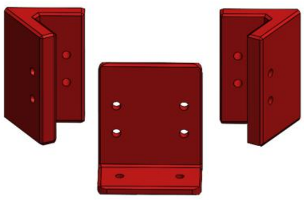
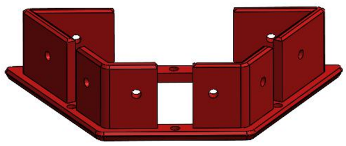
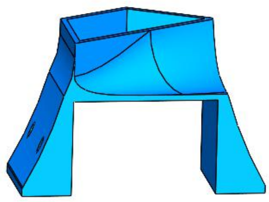
<tr><td>Magazine</td><td>
Figure 4.60: Body Magazine Revision 1</td><td colspan="2">
Figure 4.61: Final Revision of Body Magazine</td></tr>
<tr><td>Brackets</td><td colspan="3">
Figure 4.62: Final Revision of Body L-Brackets</td></tr>
<tr><td>Body magazine’s holder</td><td>
Figure 4.63: Body Magazine Holder Revision 1</td><td>
Figure 4.64: Body Magazine Holder Revision 2</td><td>
Figure 4.65: Final Revision of Body Magazine Holder</td></tr>
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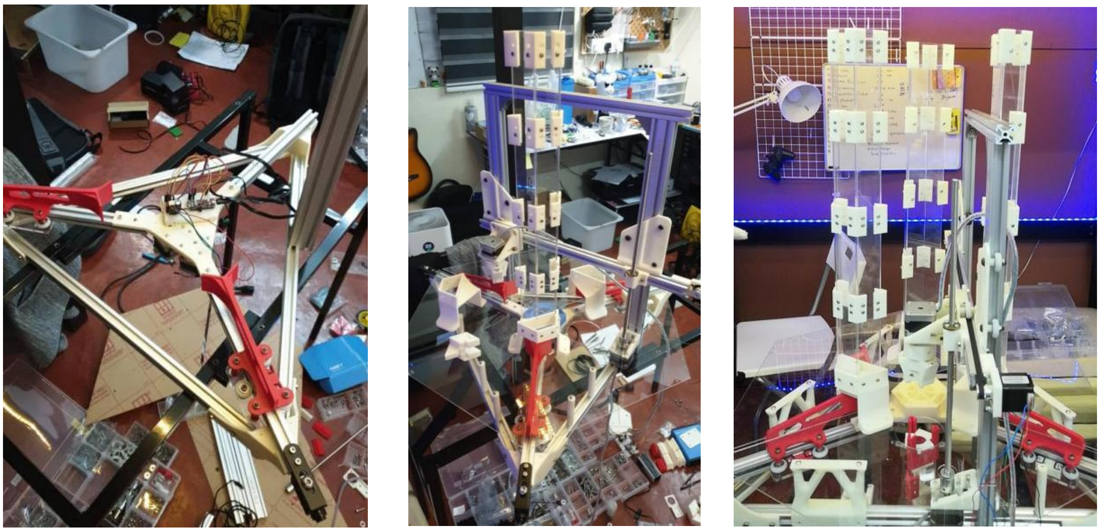
4.11 Prototype

This subtopic aimed to present the prototype that is built with 3D printed components. The main components of the system comprise key magazine, body magazine, linear actuator system, gripper, assembly acrylic board, and machine frames. The large parts such as the acrylic assembly table were laser cut as two pieces separately due to the printer's space limitations.



(a) (b) (c)

Figure 4.66: (a) Initial, (b) Second, and (c) Final Stage of Prototype

4.11.1 Assembly Operation of Prototype

There are a total of 13 steps to operate the machine. The detailed operations of the prototype are presented below.

Step 1: Reload the body magazine with the body components of the door gift.

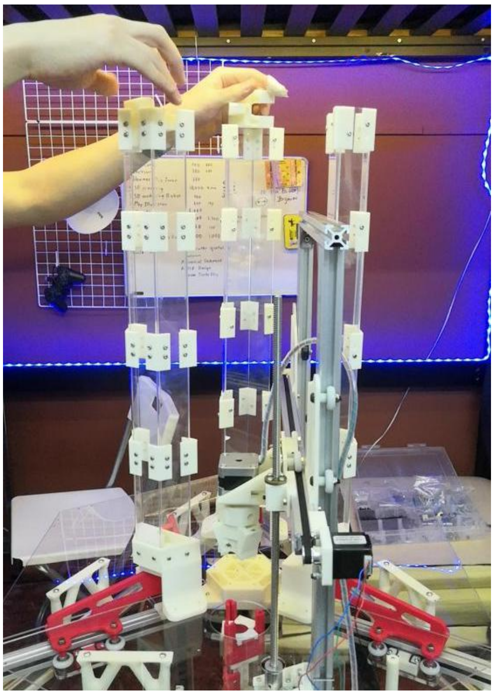


Figure 4.67: (a) Initial, (b) Second, and (c) Final Stage of Prototype

Step 2: Remove the retainer lid, load the key to the key magazine and install back the retainer lid.

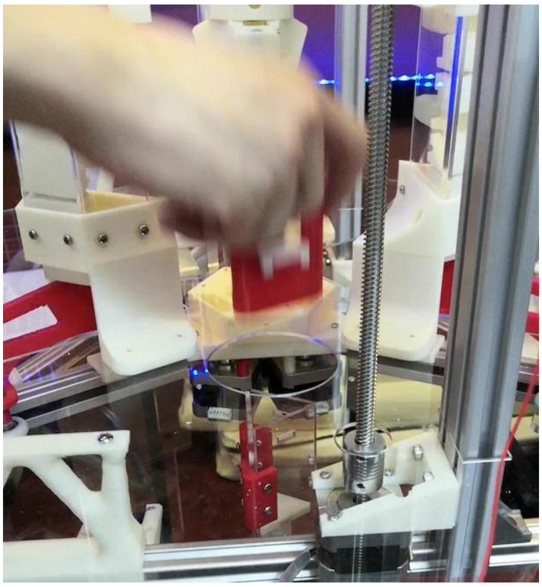


Figure 4.68: Remove the Retainer Lid

Figure 4.69: Load the key to the key magazine.

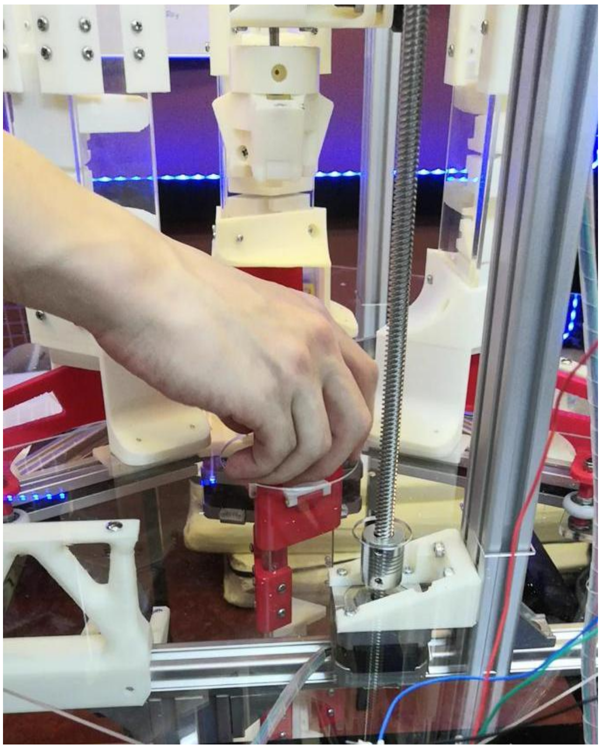


Figure 4.70: Install the Retainer Lid

Step 3: Transfer the key from the bottom of key magazine.

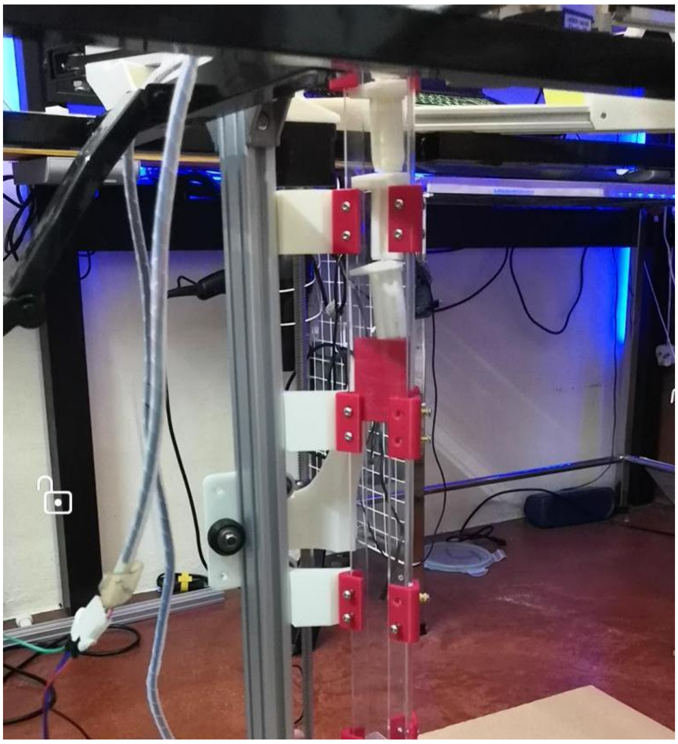


Figure 4.71: Transfer the Key using Linear Actuator

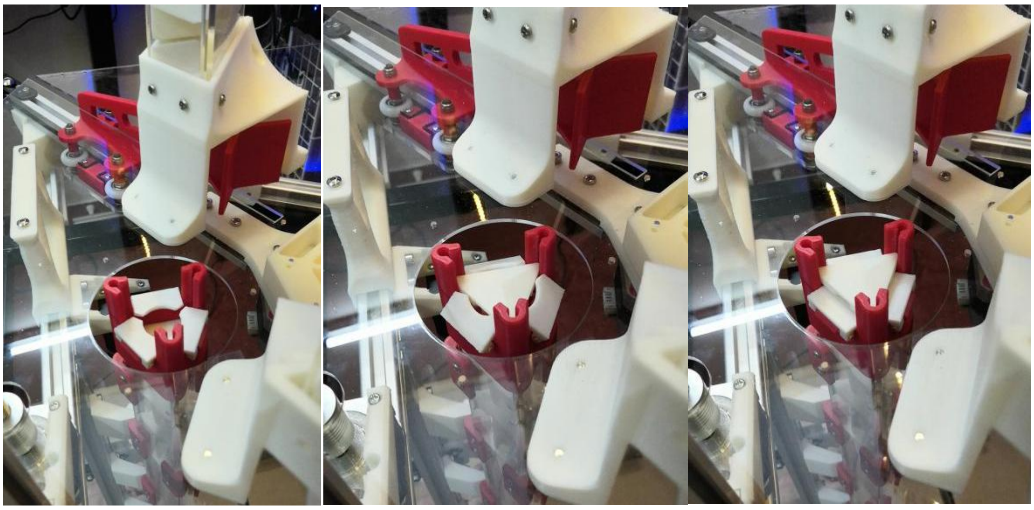


Figure 4.72: Motion of Retainer Lid

Step 4: Assemble the Body Components.

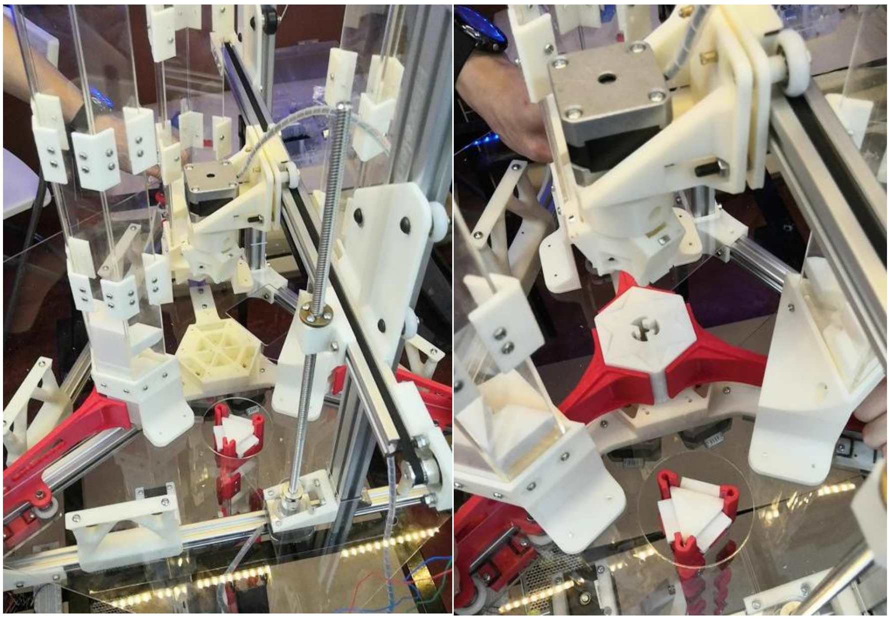


Figure 4.73: Assemble the Body Components

Step 5: Move the Gripper to the Top of Key Magazine.

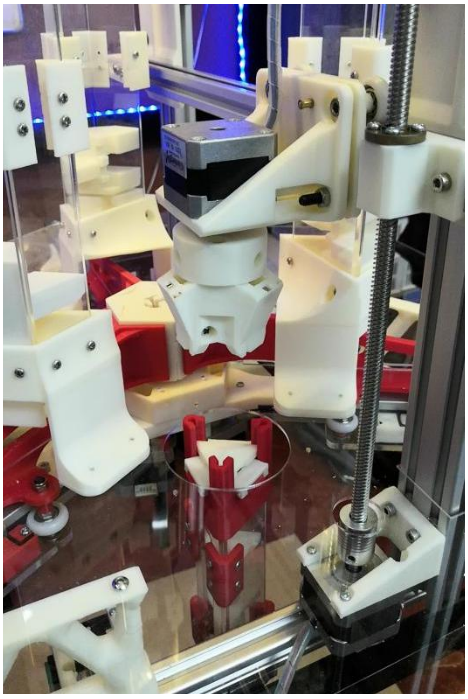


Figure 4.74: Move the Gripper to the Top of Key Magazine

Step 6: Grasp the key.

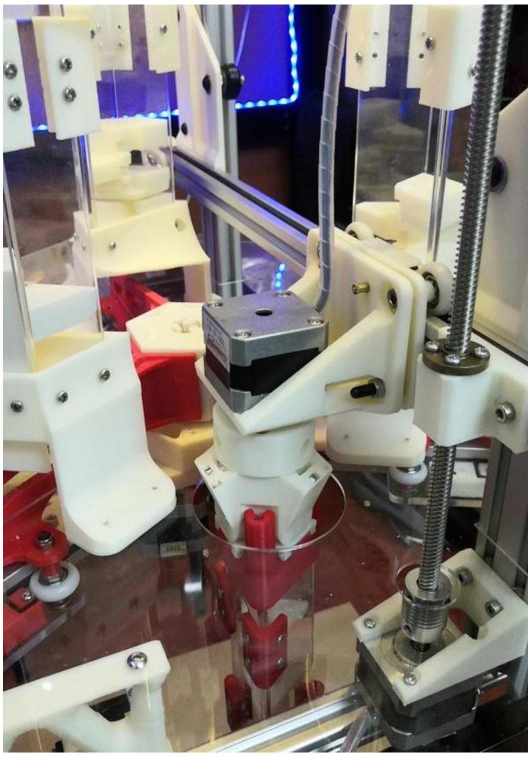


Figure 4.75: Grasp the Key

Step 7: Move gripper up.

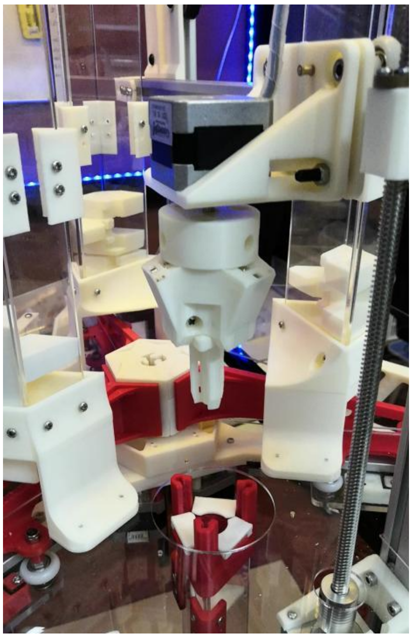


Figure 4.76: Gripper Moves Up

Step 8: Move gripper to the Top of Assembled Components.

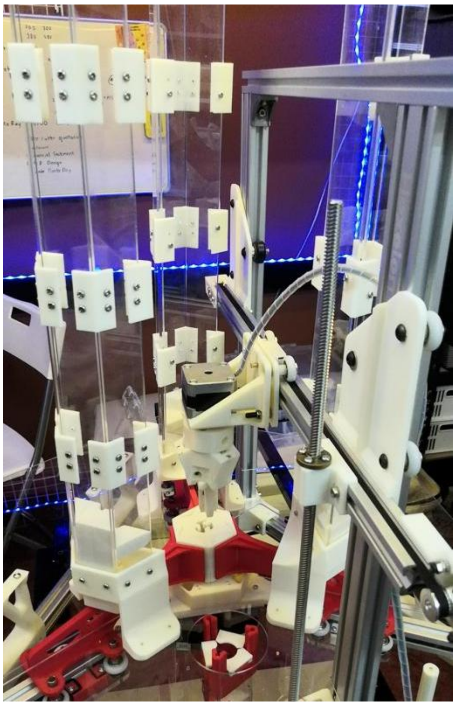


Figure 4.77: Move gripper to the Top of Assembled Components

Step 9: Insert the Key to the Assembled Components.

Figure 4.78: Insert the Key to the Assembled Components

Step 10: Rotate the Key.

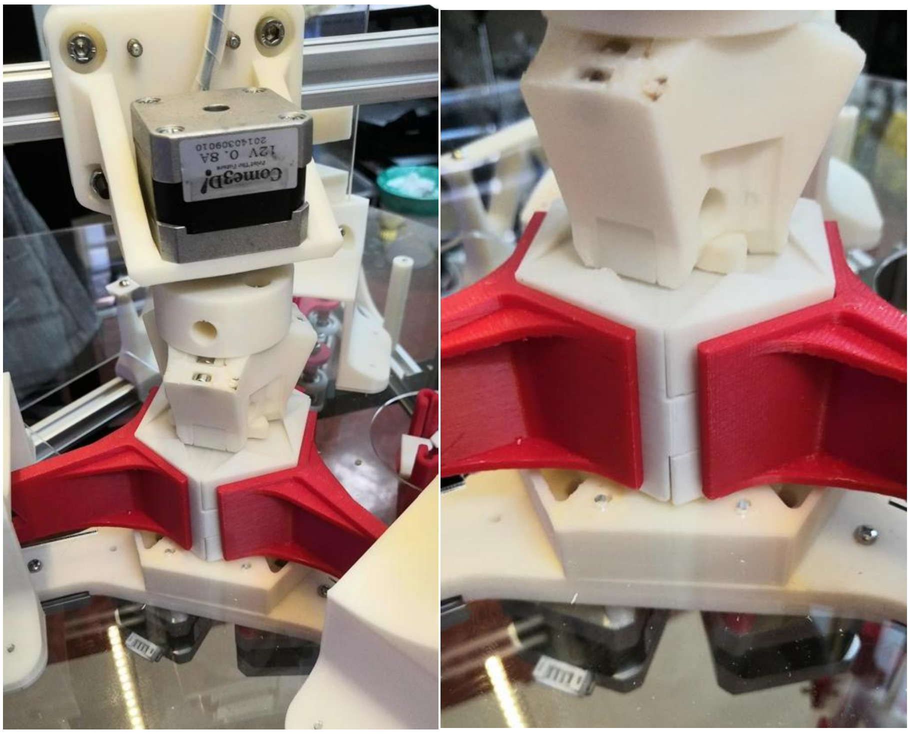


Figure 4.79: Rotate the Key

Step 11: Gripper moves up.

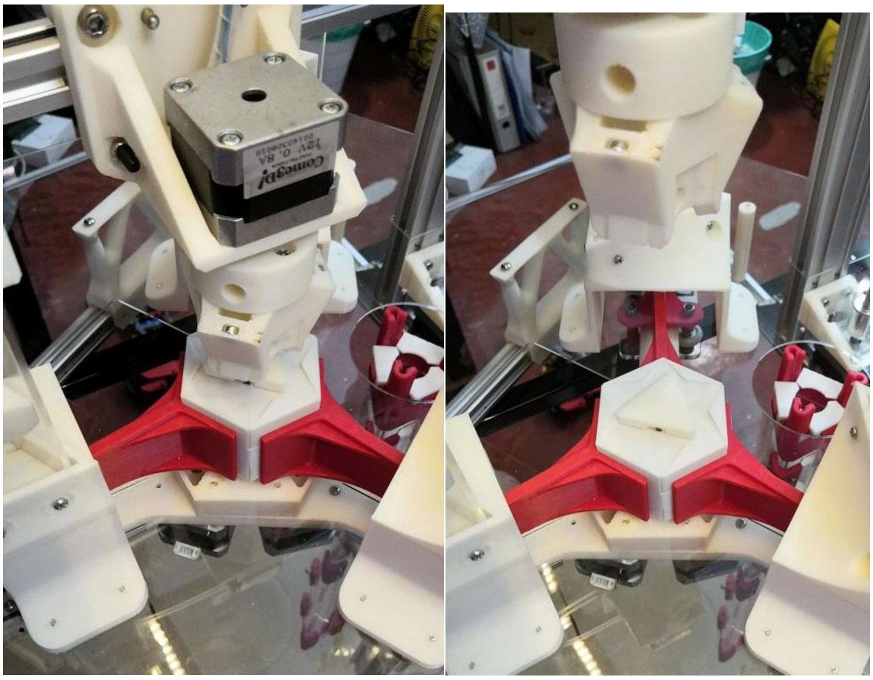


Figure 4.80: Gripper Moves Up

Step 12: Two linear actuators back to original position.

Figure 4.81: Two Linear Actuators Back to Home Position

Step 13: The remaining actuator push the assembled door gift to output zone and back to its original position.

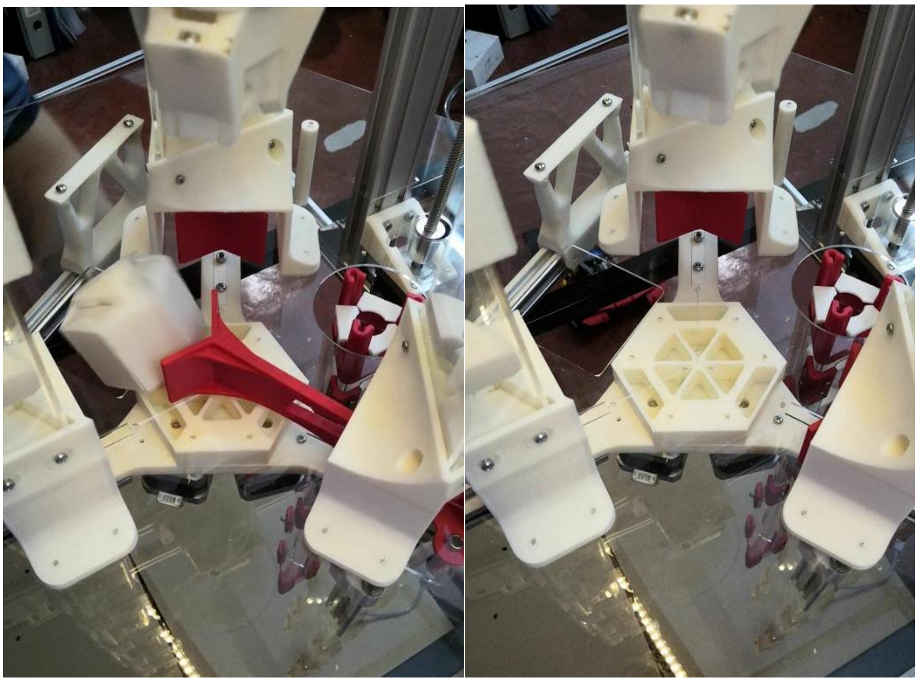


Figure 4.82: The Remaining Actuator Push the Assembled Door Gift to Output Zone

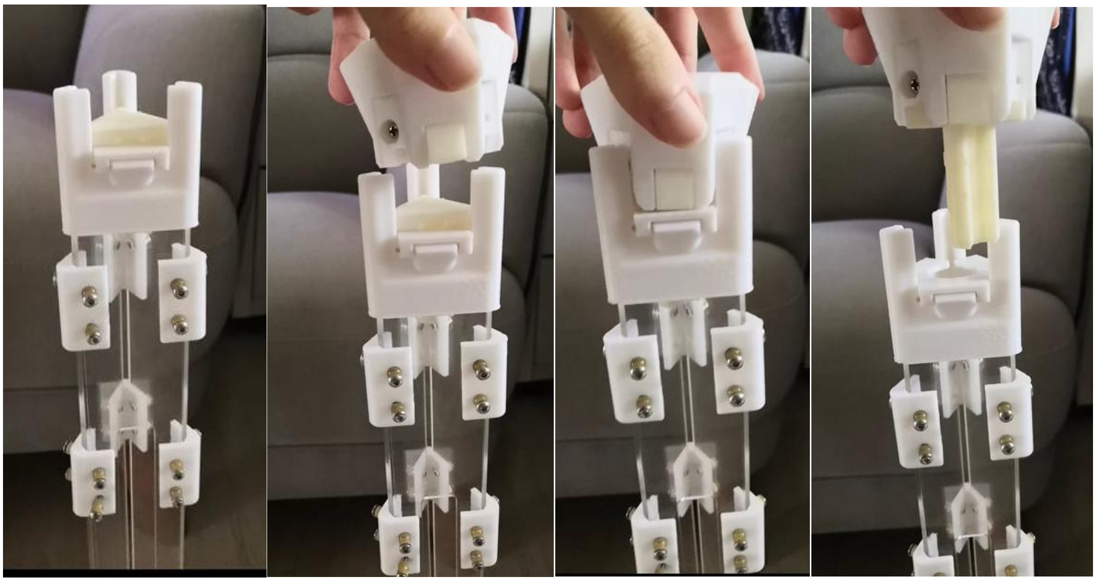


Figure 4.83: Gripping Process of the Key Components

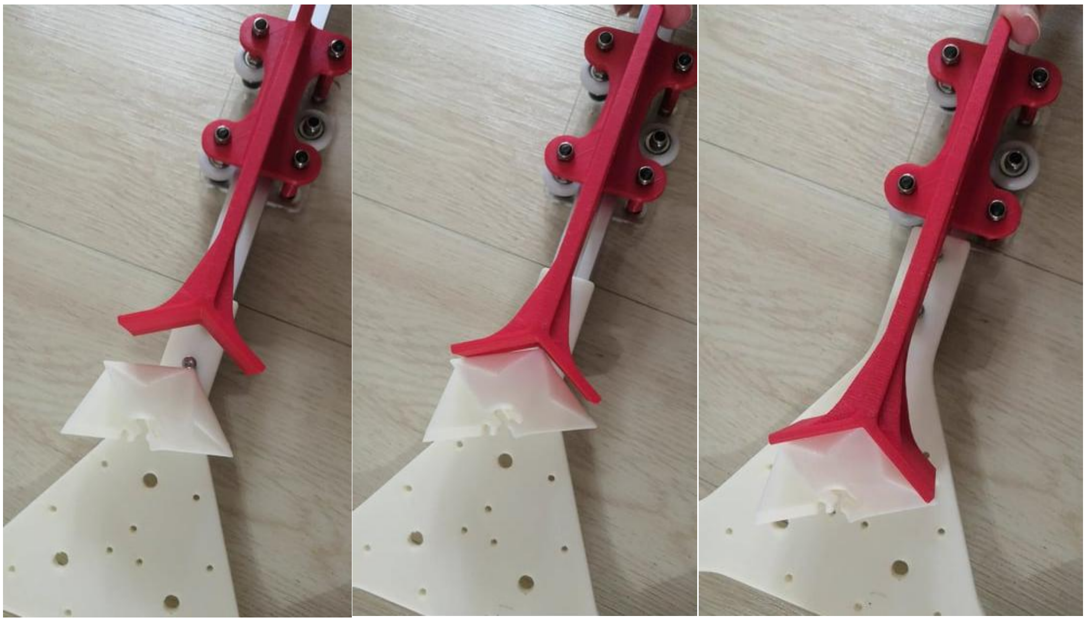


Figure 4.84: Motion of the Linear Actuator

Figure 4.85: Key Magazine Assembly

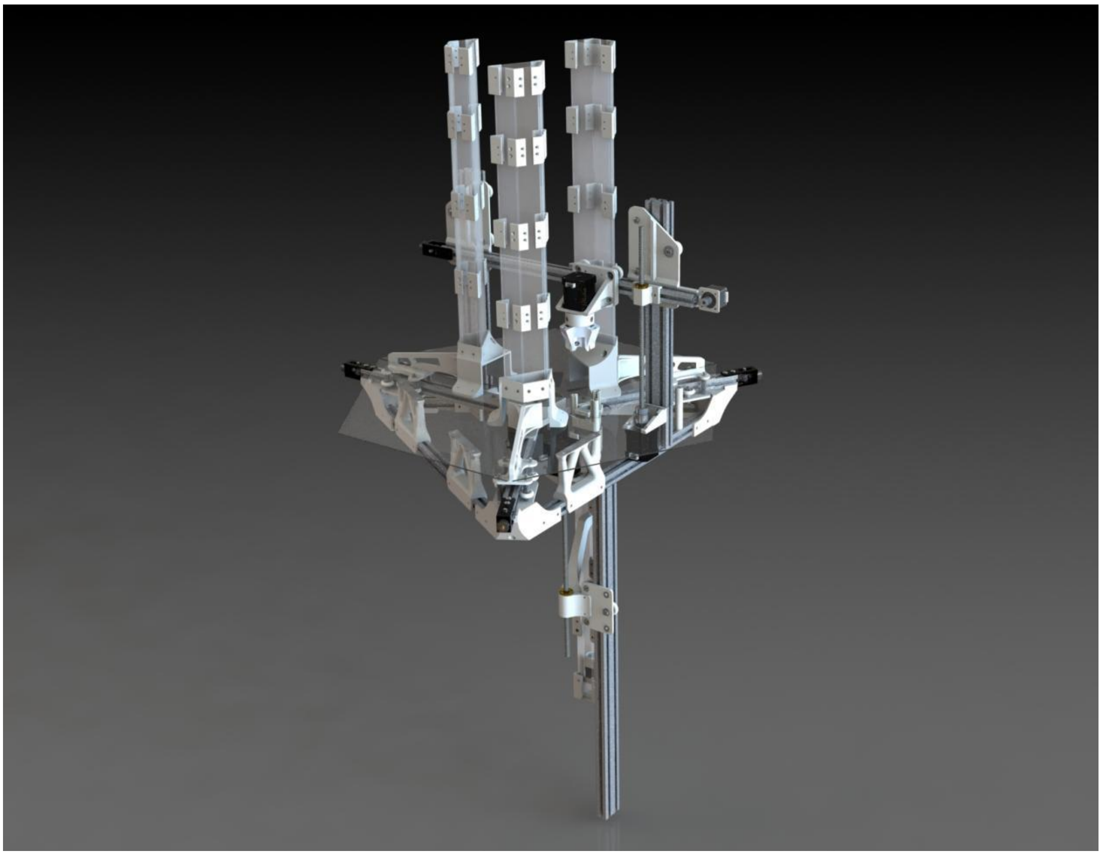


Figure 4.86: Renderings of The Automated Assembly System

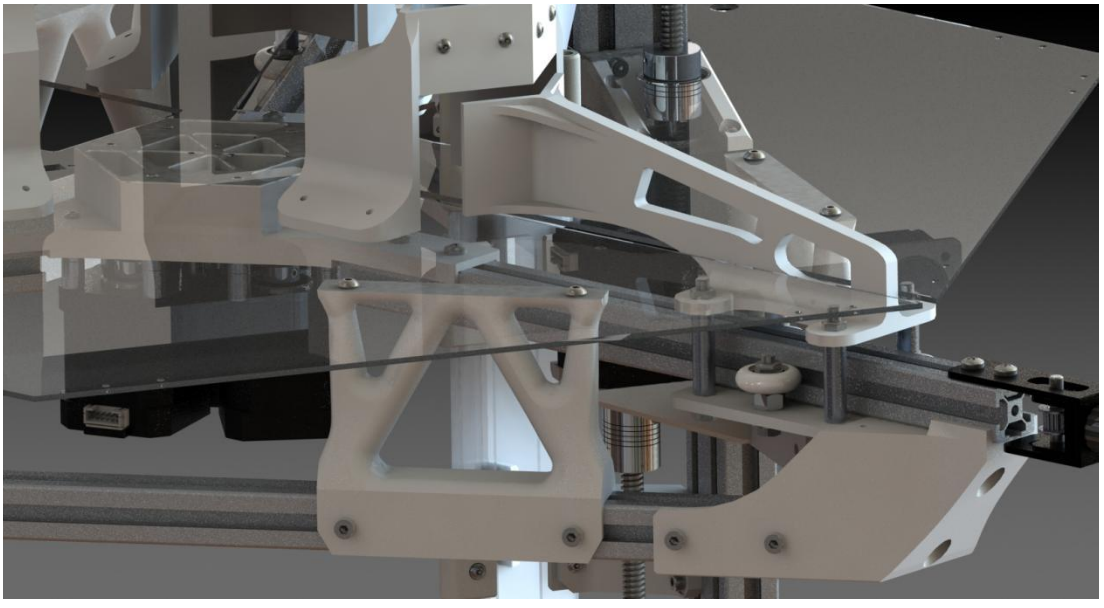


Figure 4.87: Close View Rendering of the Actuators

4.12 Topology Optimisation

Topology optimisation is the feature that aimed to reduce the overall mass and maximum displacement of a component. In other words, the manufacturing cost of the 3D printed parts can be effectively reduced. The topology study can be performed by referring to the loads, design area, or manufacturing methods. The topology optimisation of the top arm mounting is shown in Figure 4.88.

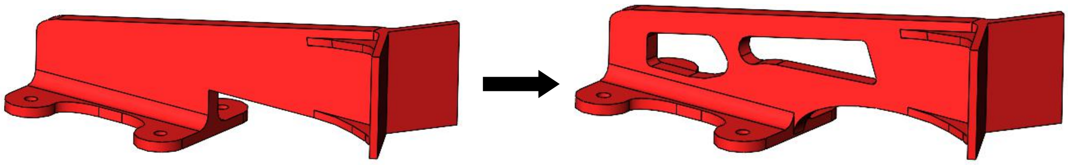


Figure 4.88: Topology Optimisation of Top Arm Mounting

4.13 Individual Project Involvement

The main responsibility and focus of my personal involvement in this project is mechanical design and prototyping. To ensure the feasibility of the design, some literature reviews and studies were conducted. The subsystems design that I had involved includes body magazine, key magazine, and linear actuators. The design was improvised and optimised to achieve better system performance. The mechanical engineering design skills have improved upon the project completion. Meanwhile, the 2D technical drawings were generated. I was also involved in building the prototype. The detailed tasks during these 14 weeks were tabulated in Table 4.6.

Table 4.6: Personal Involvements in the Project

Week	Tasks	Description
1	Title Identification	Identify the title, aim and objectives of the project.
2	Mechanical Design	Conceptual design on automated assembly system.
3	Literature Study	Automated assembly machines, automation control systems.
4	Literature Study	End effector, industrial motor.
5	Literature Study	Sensors in automation.
	Mechanical Design	Improvise the design of compliant clip.
6	Literature Study	Compliant mechanism, Thermoforming, 3D printing, Rotary Table.
	Mechanical Design	Thermoformed key tray design.
7	Literature Study	Research on industrial motor. Motor and timing belt selection.
8	Mechanical Design	Replace key tray with key magazine. Implement drum and pillar for ease of loading and unloading process.
	Prototype	Learn to operate 3D printer.
9	Mechanical Design	Detailed design and drawing on key magazine.
10	Mechanical Design	Detailed design and drawing on body magazine.
11	Prototype	3D Print and design validation of key and body magazines.
	Mechanical Design	Detailed design and drawing on linear rail arm actuator.
12	Mechanical Design	Optimise and finalise the design. Generate 2D drawing.
	Prototype	3D Print and design validation of linear rail arm actuator.
13	Mechanical Design	Generate 2D drawing.
	Prototype	Assemble the remaining subsystems.
14	Report writing and Presentation	Writing the final report and prepare presentation.

4.14 Problems Encountered

There were several issues encountered when carrying out the project, for instance, communication barrier, delay of components, limited industrial experiences, and limited software resources, which give rise to schedule delays. In order to accomplish effective problem-solving, several viable and suitable solutions were established according to the root problems.

4.14.1 Delay of Components

The project faced delay, disruptions, and some uncertainties of completion owing to the Covid-19 pandemic. The prototype was built for design validation and the design optimization process. However, the ordered parts consumed a long time to be delivered in the current situation. In order to accelerate the progress of building the prototype, some of the parts were 3D printed by using the 3D printer that is owned by one of my friends, Lim Kai Wen. The 3D drawings of each part were transferred to a software, CURA to proceed with 3D printing. A better insight into the 3D printing technology was gained while operating the 3D printer.

In order to accelerate the progress of building the prototype, the parts were 3D printed by using the 3D printer as shown in Figure 4.90 that is owned by one of the teammates, Lim Kai Wen. The 3D drawings of each part were transferred to a software, CURA to proceed with 3D printing. A better insight into the 3D printing technology were gained while operating the 3D printer.

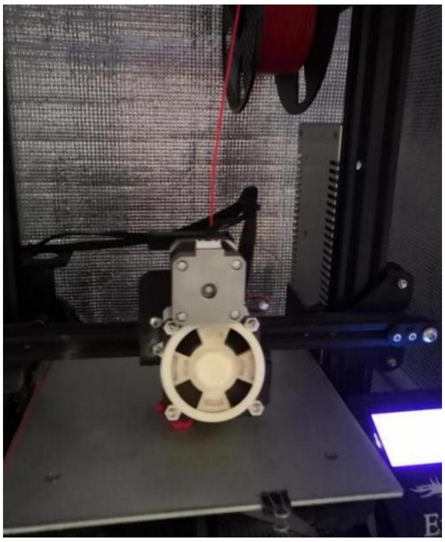


Figure 4.89: 3D Printer

4.14.2 Limited Industrial Experience

The initial design approach of the system possesses a high rate of failure due to insufficient industrial experiences and relevant mechanical design knowledge. Unlike machining, 3D printed parts require more design iterations and considerations. Hence, the literature study and review on mechanical engineering design, automated assembly machines, and 3D printing were continuously conducted to further improve the understanding. Despite the 3D printing process encountered a series of failures, this project has provided an opportunity on acquiring knowledge on 3D printing technology and industrial automation. Each of these failures was clearly investigated to avoid falling into the same old trap again.

4.14.3 Limited Software Resources

The software Solidworks was downloaded for the 3D modeling function. However, the 2021 version occurred several issues while performing assembly, mating, simulation, and motion analysis. The cause of the limited resource monitor is due to the GDI Objects limit of the Window OS. This issue had negatively affected the smoothness of conducting this project. To solve this issue, the license on the premium and full version of Solidworks with the features are requested to be provided.

4.15 Procurement List

The total cost used for this project are RM 1242.16. Most of the components were bought from online shopping platform, Shopee. The details of the procurement list were tabulated in Table 4.7.

Table 4.7: Procurement List

No.	Product	Specifications	Price per pcs (RM)	Quantity	Total Price (RM)	Image
1.	Aluminium Profile 2020	Model 2020, 1 meter	11.00	3	33.00	
2.	Aluminium Profile 2040	Model 2040, 1 meter	13.50	2	27.00	
3.	Guesset Element Corner Fitting L Bracket Angle Connector	Type: L-Bracket Model No.: 2028 Color: Silver/black Material: Die cast aluminium	2.50	10	25.00	
4.	GT2 Open Timing Belt (6mm) with Aramid Fibre Core	Model No: GT2 Pitch: 2mm Width: 6mm	8.00	3	24.00	
5.	High Tensile Cap Screw	M5 x 45mm Full Thread	0.70	50	35.00	
		M5 x 25mm Full Thread	0.50	75	37.50	
		M5 x 20mm Full Thread	0.45	50	22.50	
6.	Lock Washer	Model: M5	0.32	50	16.00	

7.	Nylon Plastic Carbon Steel Pully Wheels Roller Groove Ball Bearings	Model: 625ZZ Injection Material: White POM Bearing Material: High Carbon Steel Inner diameter: 5 (mm) Outside diameter: 21.5 (mm) Thickness: 7 (mm)	1.32	25	33.00	
8.	Nylon Lock Nut 304 Stainless Steel Hexagon	Model: M5	0.27	50	13.50	
9.	SS Flat Washer M2 ~ M10 (Stainless Steel 304 FW)	Stainless Steel 304 FW, Model = M5	0.15	50	7.50	
		Stainless Steel 304 FW, Model = M6	0.20	50	10.00	
10.	SS Socket Button Cap Screw	M4 x 10mm Full Thread	0.25	50	12.50	
		M3 x 12mm Full Thread	0.30	50	15.00	
11.	Stainless Steel Button Head Screw	M4 x 5mm	0.30	50	15.00	

12.	Synchronous Belt Tensioner	Color: Black Material: Aluminium Alloy (CNC fine finishing treatment) Application: for 6mm belt	30	3	90	
13.	Nema 17	Bipolar 4 wire length: 39 inches Nema 17 size: 42 x 42 x 37 mm 1.3 A per phase, torque: 0.3 N/m	26.00	3	78.00	
14.	16T W6 B5	Material : Aluminium Suitable for belt size 6 mm Number of Teeth : 16 Bore /Hole Size : 5 mm	5.90	3	17.70	
15.	Hex Socket M4 Screw 10 mm	Drive Style: Hex Socket Screw Type: Machine Screws Head Style: Flat Material: Alloy Steel Model Number:M2 M2.5 M3 M4	4.54	10	45.40	

16.	Hex Socket Cap Head M4 Screws	Size: B18 6.7M-M4 x 0.7 x 5mm Material: A2 Grade Stainless Steel 304	1.53	12	18.36	
17.	Hex Socket Cap Head M3 Screws	Material: A2 Grade Stainless Steel 304	0.99	12	11.88	
18.	Polycarbonate Solid Sheet (PC Sheet) - 2 mm	Thickness: 2 mm Size: A2 (42.0 x 59.4 cm) Color: Transparent	33.90	1	33.90	
19.	Polycarbonate Solid Sheet (PC Sheet) - 3 mm	Thickness: 3 mm Size: A2 (42.0 x 59.4 cm) Color: Transparent	51.39	1	51.39	
20.	ABS Filament	Colour: Red Width: 1.75mm Weight: 1kg	59.34	1	59.34	
		Colour: Natural Width: 1.75mm Weight: 1kg	59.89	1	59.89	
21.	Pan Screw M3 x 30	HD M/C Screw M3	0.063	100	6.30	-
22.	Aluminium Profile parts and Accesories	-	10.00	1	10.00	-
23.	Arcylic	(2 x 620 x 620) mm	42.00	2	84.00	-
		(3 x 600 x 420)	30.00	3	90.00	

		mm				
		(3 x 300 x 420)	15.00	2	30.00	
24.	Laser cutting fees		156.00	1	156.00	-
25.	Laser engraving fees		3.00	10	30.00	-
26.	Shipping Fees		43.50	1	43.50	-
				Total Price	**RM 1242.16**	

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In conclusion, optimizing the highly sustainable and reliable assembly machines is an effective solution to improve the quality and productivity of the product. This industrial-based project is linked with Greatech Integration (M) Sdn. Bhd. The assembly machines provide a significant contribution to the field of industrial automation and robotics with the integration of an automated assembly system that can assemble door gifts. The automated assembly system offers leading advantages in refilling components as the pillars and drum can be removed with the empty magazines. Hence, the objectives of enhancing the reliability of assembly lines with lesser human labor and time required are achieved.

5.2 Recommendation for Future Work

The current prototype is able to assemble ten door gifts. Considering that the loading process is relatively cumbersome, the magazine removal system is implemented to remove the magazines, drum, and pillar at one time. Hence, the magazine drum and pillar systems are recommended to implement for better efficient loading process and shorter cycle time required. The empty magazines can be removed easily and replaced by the loaded magazines. In order to rotate the drum of the magazines, a GT2 timing belt and pulley are used. This system provides enhanced productivity and efficiency.

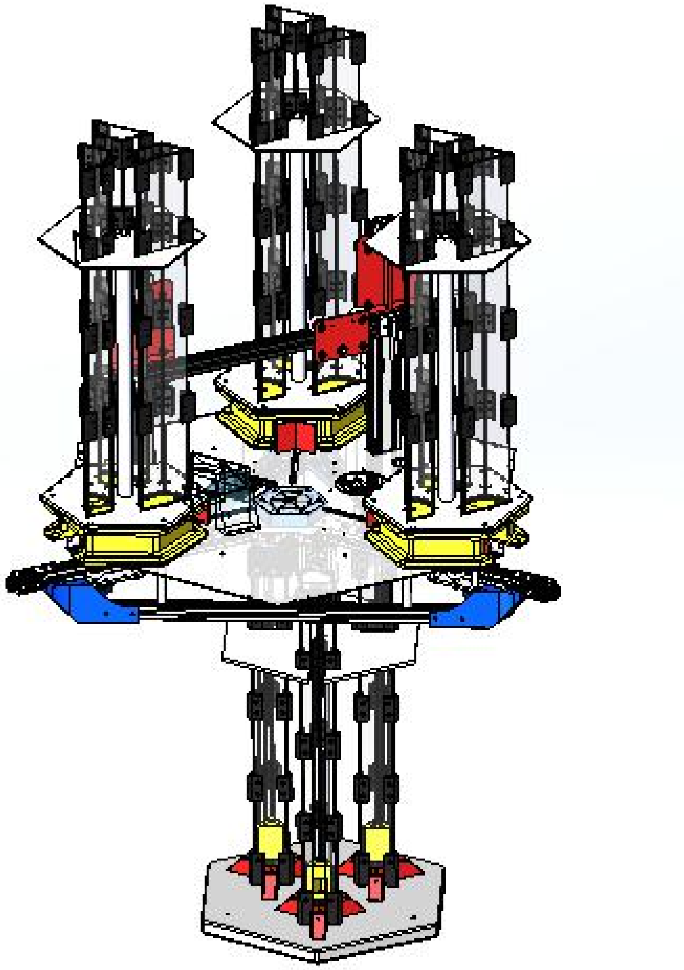


Figure 5.1: Automated Assembly Machine with Magazine Removal System

Table 5.1: Main Components of Automated Assembly System

Part No.	Main Components	Quantity
a	Body magazines	9
b	Key magazines	3
c	Linear actuator for body magazines	3
d	Linear actuator for key magazines	1
e	Gripper	1
f	Main assembly table (acrylic)	1
g	Magazine's Pillars	2

5.2.1 Key Magazine with Drum and Pillar System

Figures 5.2 and 5.3 illustrate the 3D modeling design of the key magazine with drum and pillar system. It consists of three key magazines and a GT2 timing belt and pulley are used to rotate the magazine system. The motor is designed and programmed to rotate at 120°once ten door gifts are assembled. This system can load up to 30 keys in one circle.

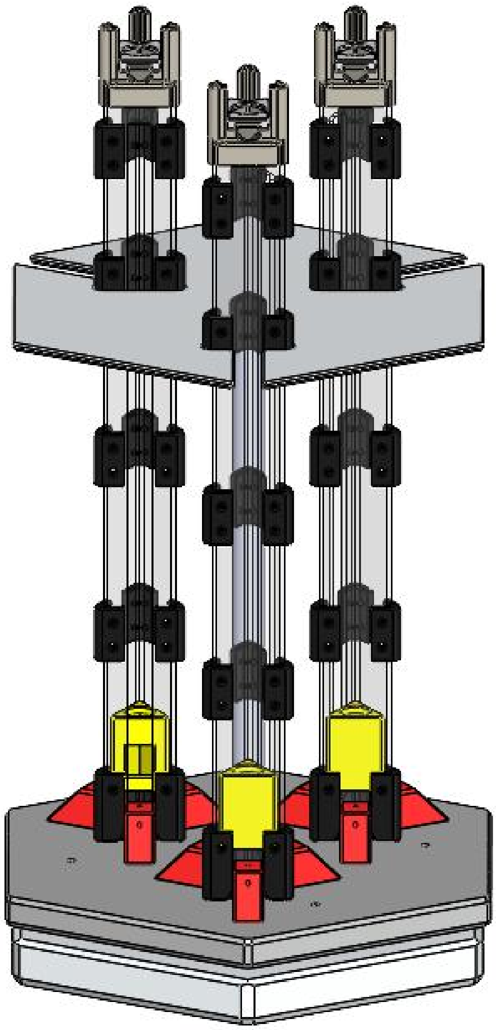


Figure 5.2: Key Magazine Main Assembly

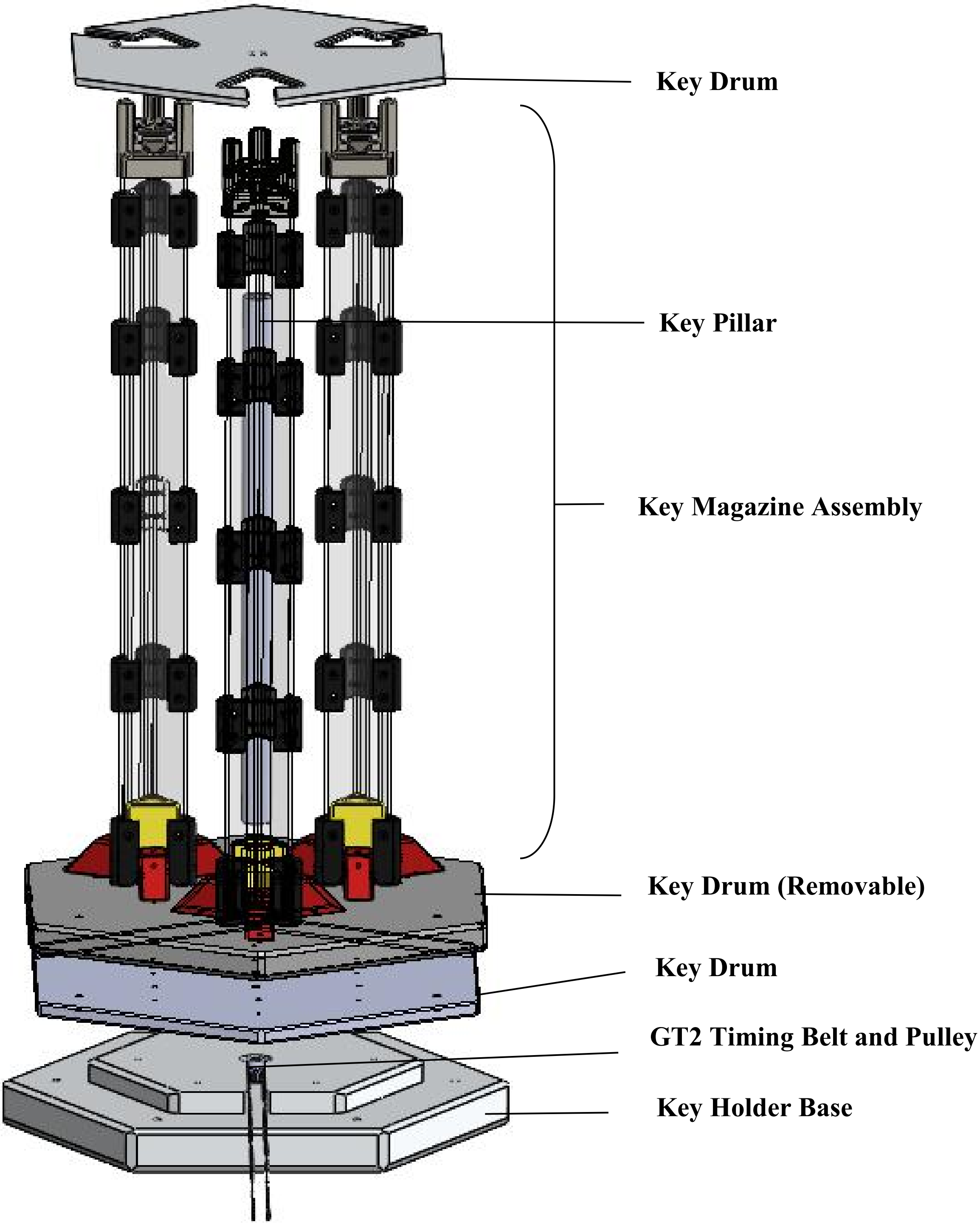


Figure 5.3: Key Magazine Main Assembly (Exploded View)

5.2.2 Key Drum and Pillars

Figure 4.21 shows the key drum and pillar of the key magazines. The GT2 timing belt will be inserted into the bottom base of the drum. Hence the upper drum that is attached to it can be rotated. To simplify the loading and unloading process the drum, pillars, and magazines can be removed at one go. This design is unable to apply a compliant mechanism as the height of the system is too high, which could possibly lead to unstable. Hence, the removable drum is screwed with the drum base.

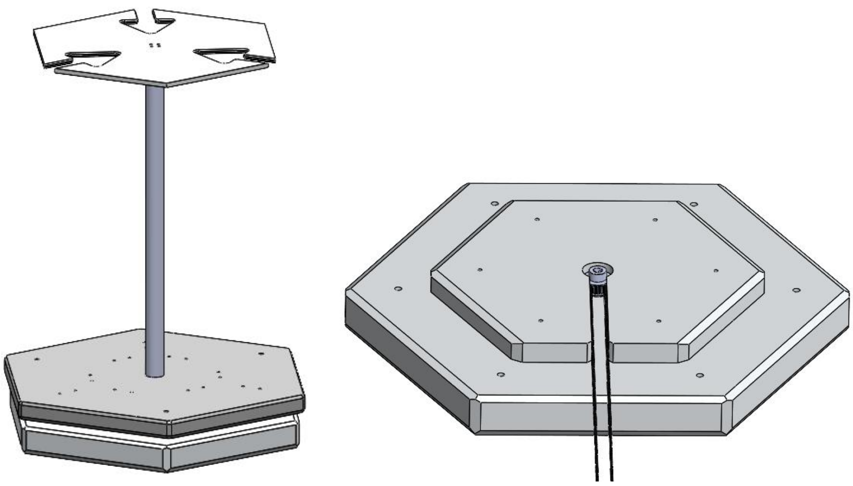


Figure 5.4: Key Drum and Pillar

5.2.3 Body Magazine with Drum and Pillar System

The 3D modeling design of the body magazines with drum and pillar system is presented in Figure 5.5. The main assembly body magazine system is made up of 9 body magazines, which can accommodate 90 body components of the door gift. Similar like the key magazine, the drum and pillar system is implemented to boost the efficiency with lesser effort and time required.

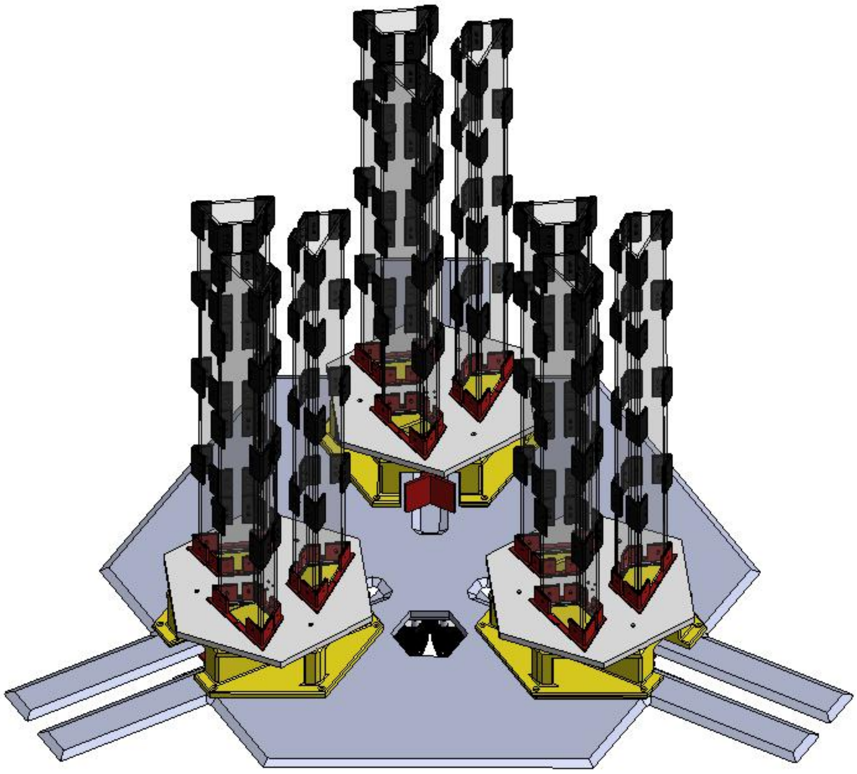


Figure 5.5: Body Magazines Main Assembly

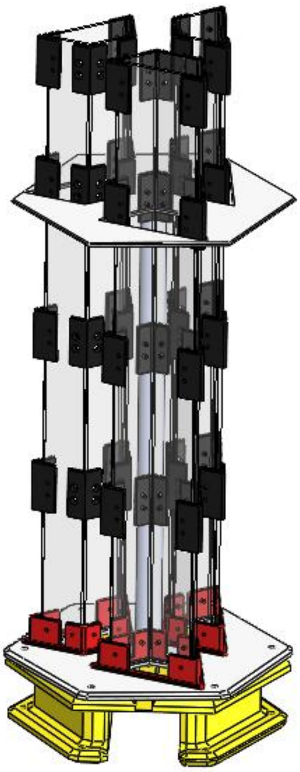


Figure 5.6: Body Magazines with Drum and Pillar System

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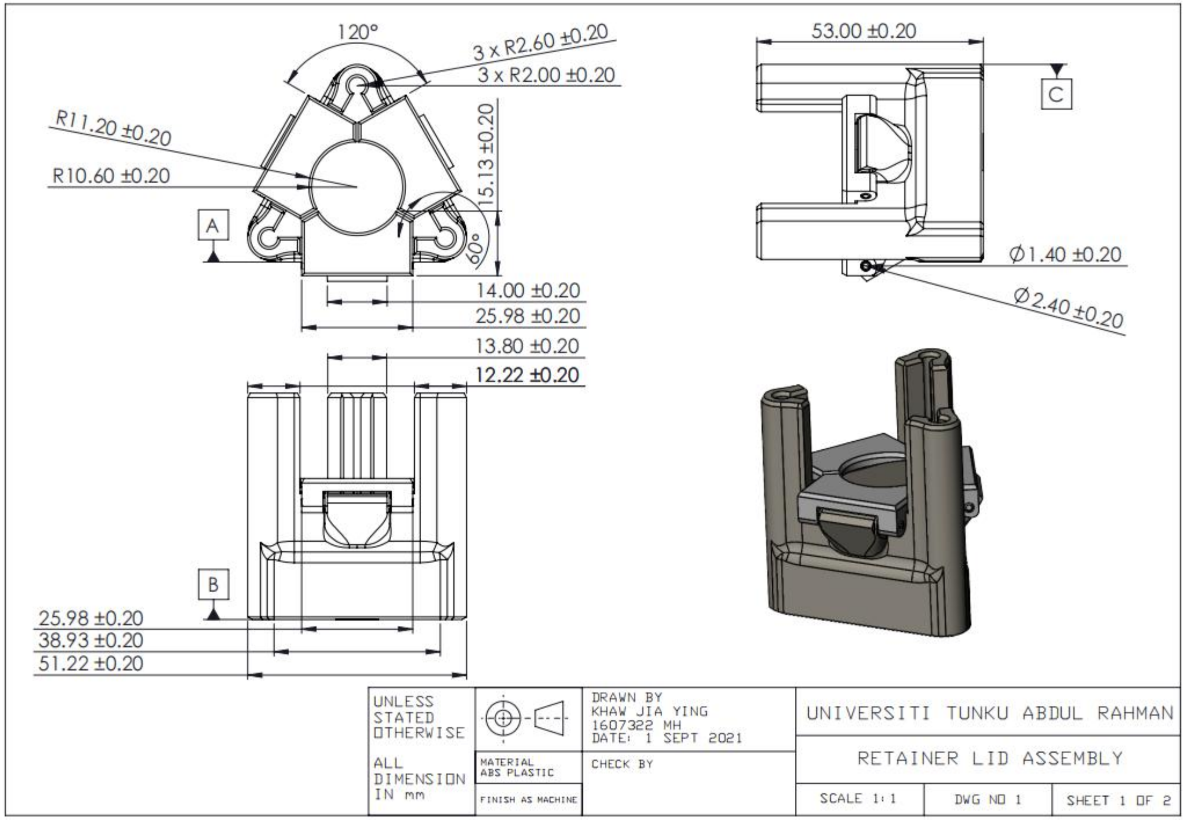
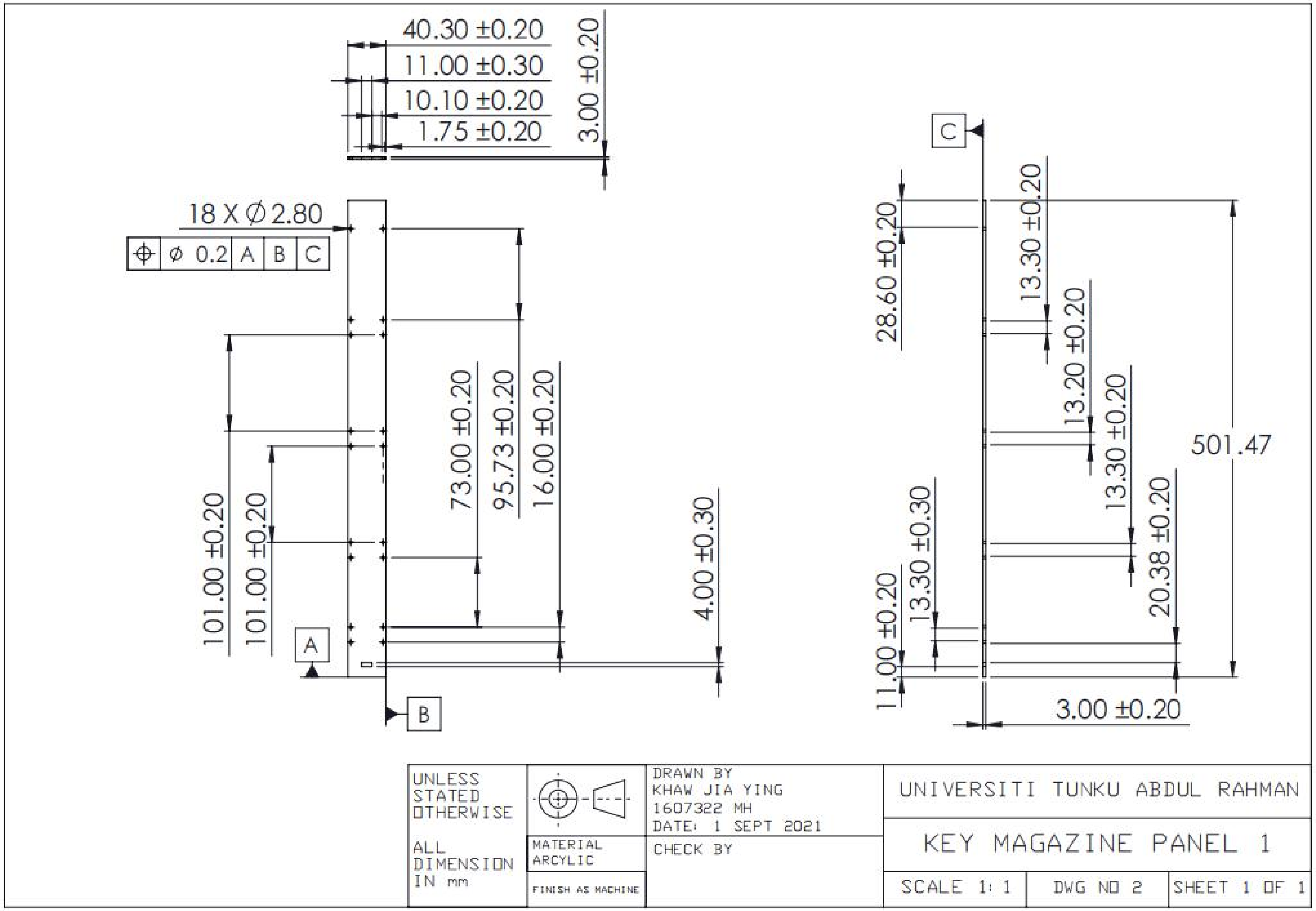
APPENDICES

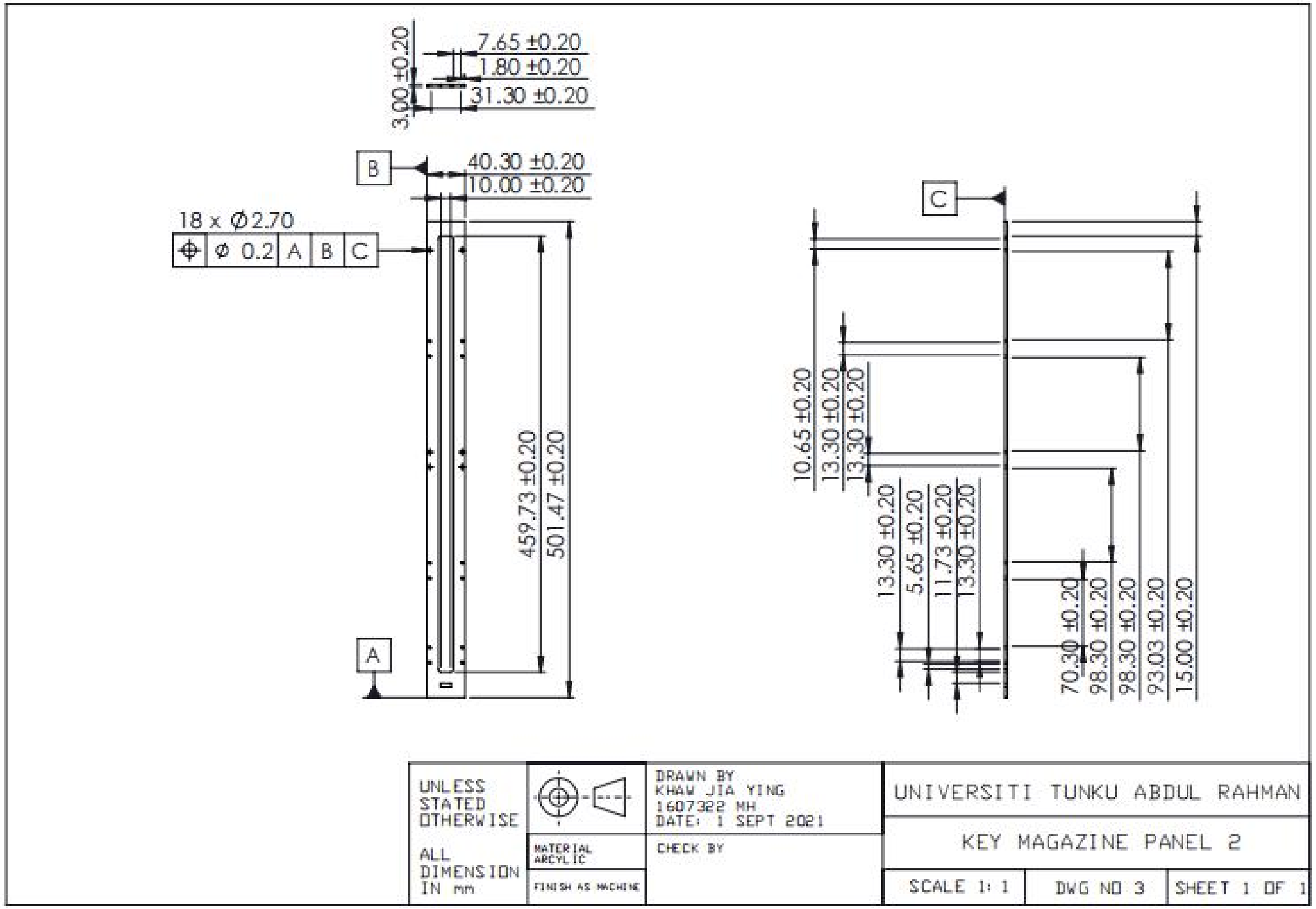
APPENDIX A: 2D Drawings



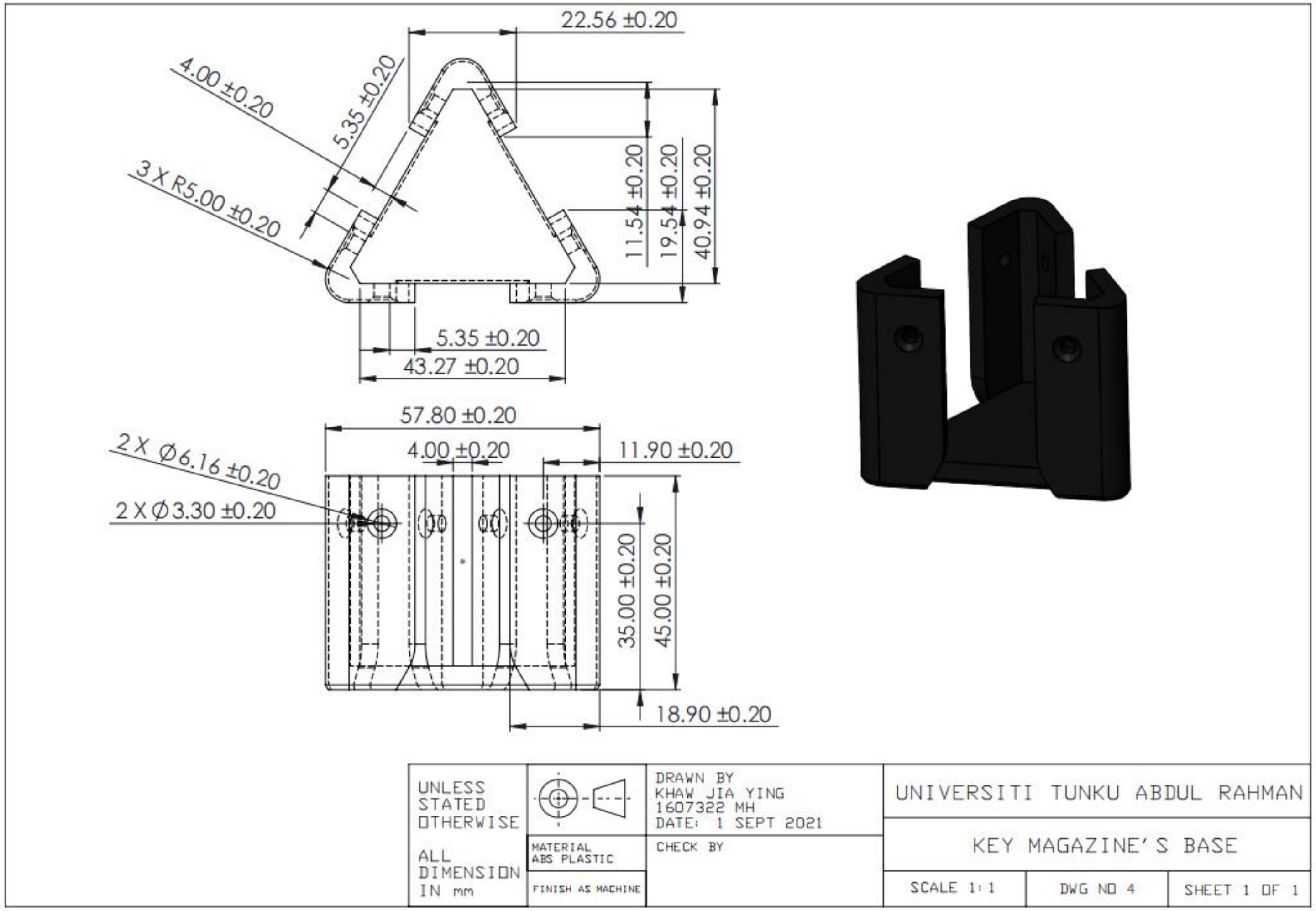
Drawings A-1: Technical Drawing of Retainer Lid Assembly



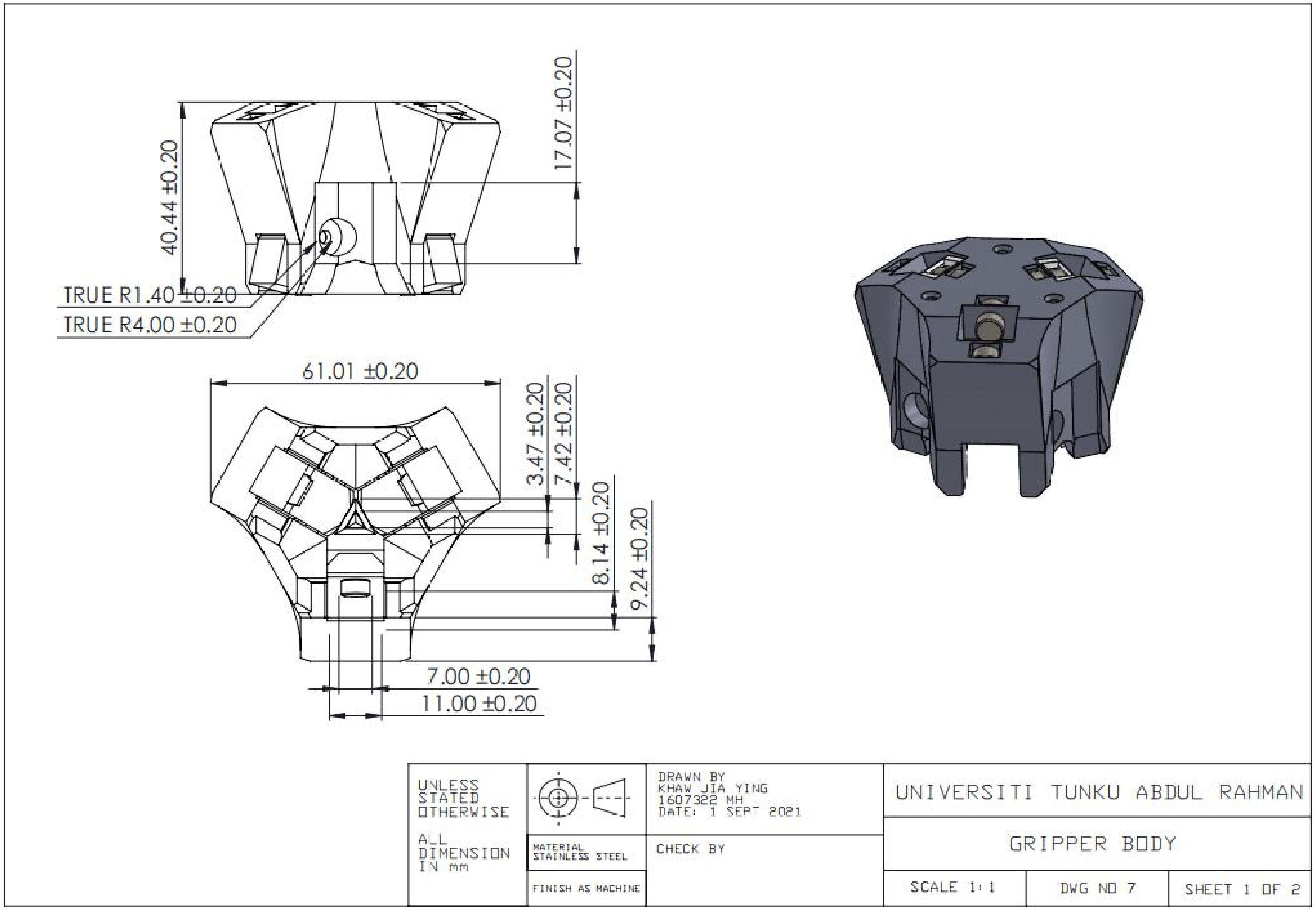
Drawings A-2: Technical Drawing of Key Magazine Panel 1



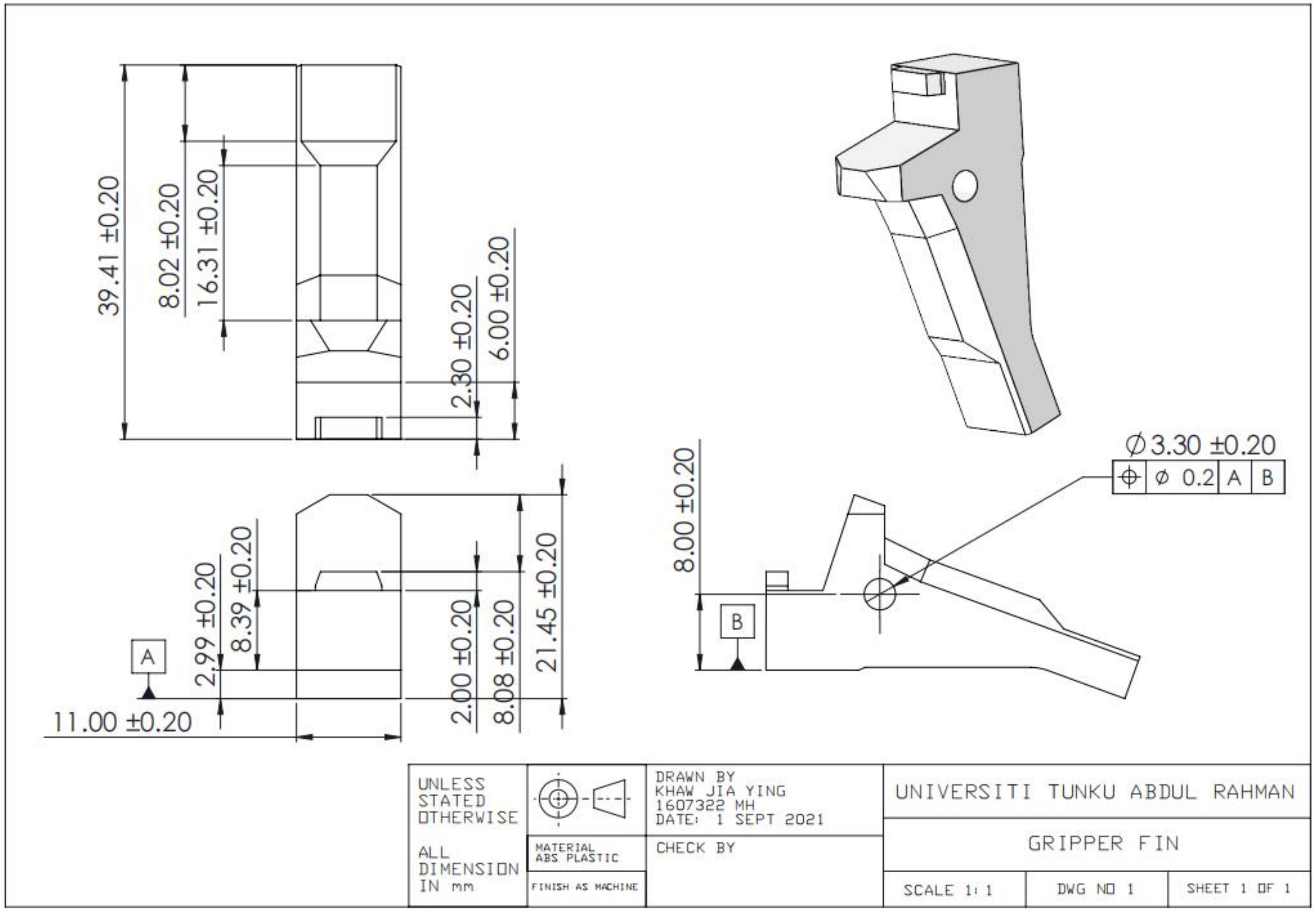
Drawings A-3: Technical Drawing of Key Magazine Panel 1



Drawings A-4: Technical Drawing of Key Base



Drawings A-5: Technical Drawing of Gripper Body



Drawings A-6: Technical Drawing of Gripper Fin

APPENDIX B: Photos

Photo B-1: Prototype Building

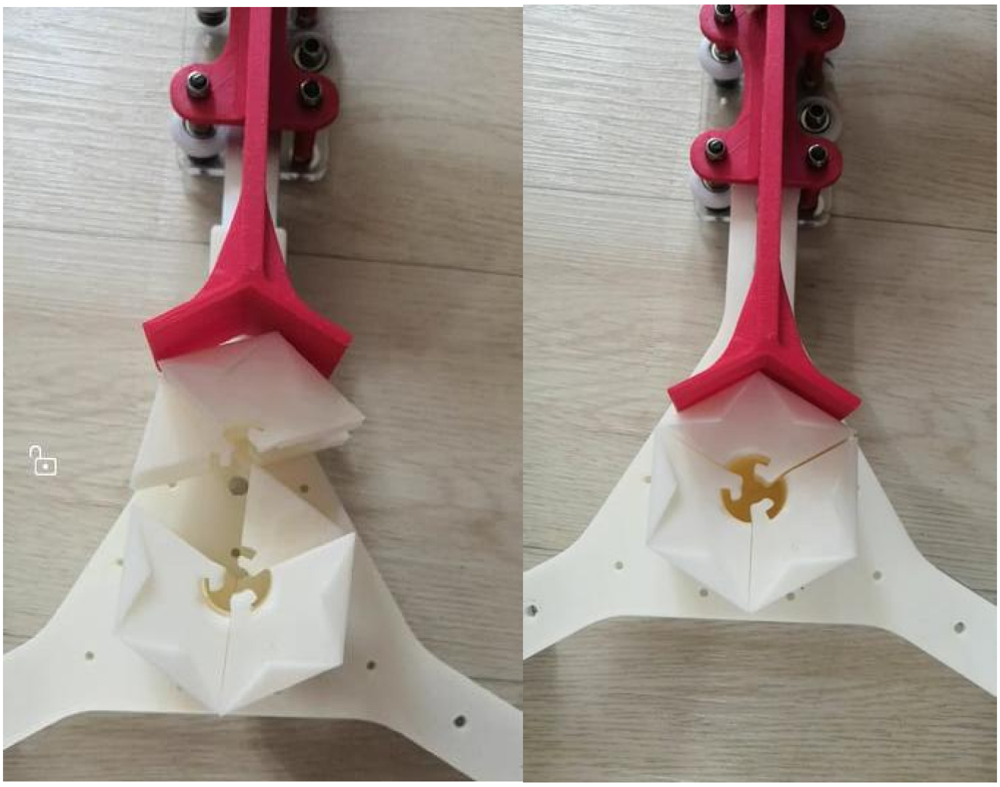


Photo B-2:Motion of the Linear Actuator (With Body Components)

Photo B-3: Linear Actuator Prototype

Photo B-4: Belt Mounting

Photo B-5: Top Arm Mounting

Photo B-6: Revision of Key Magazine

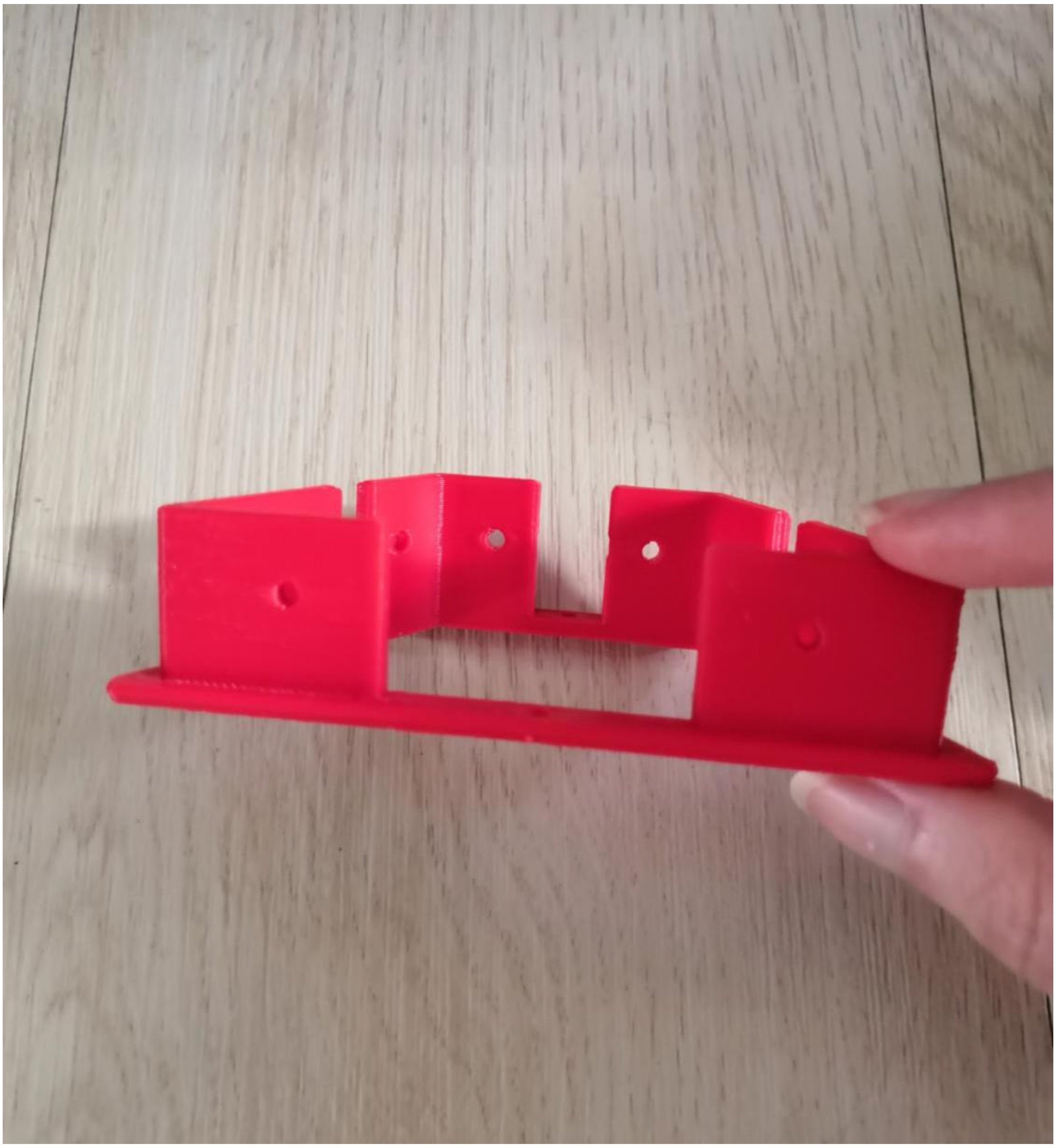


Photo B-7: Holder of Body Magazine

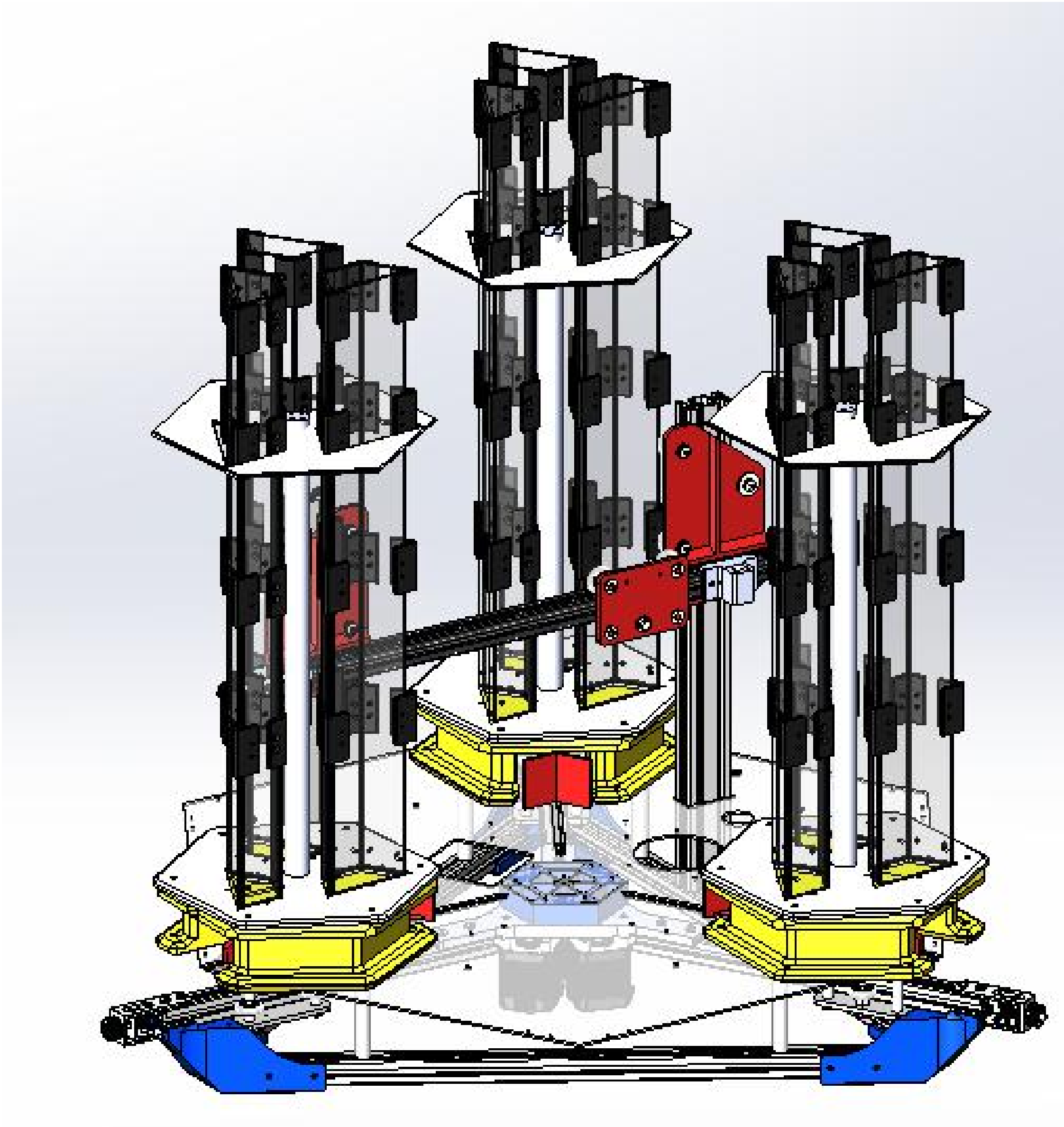


Photo B-8: Body Magazine Main Assembly with Gripper Rail

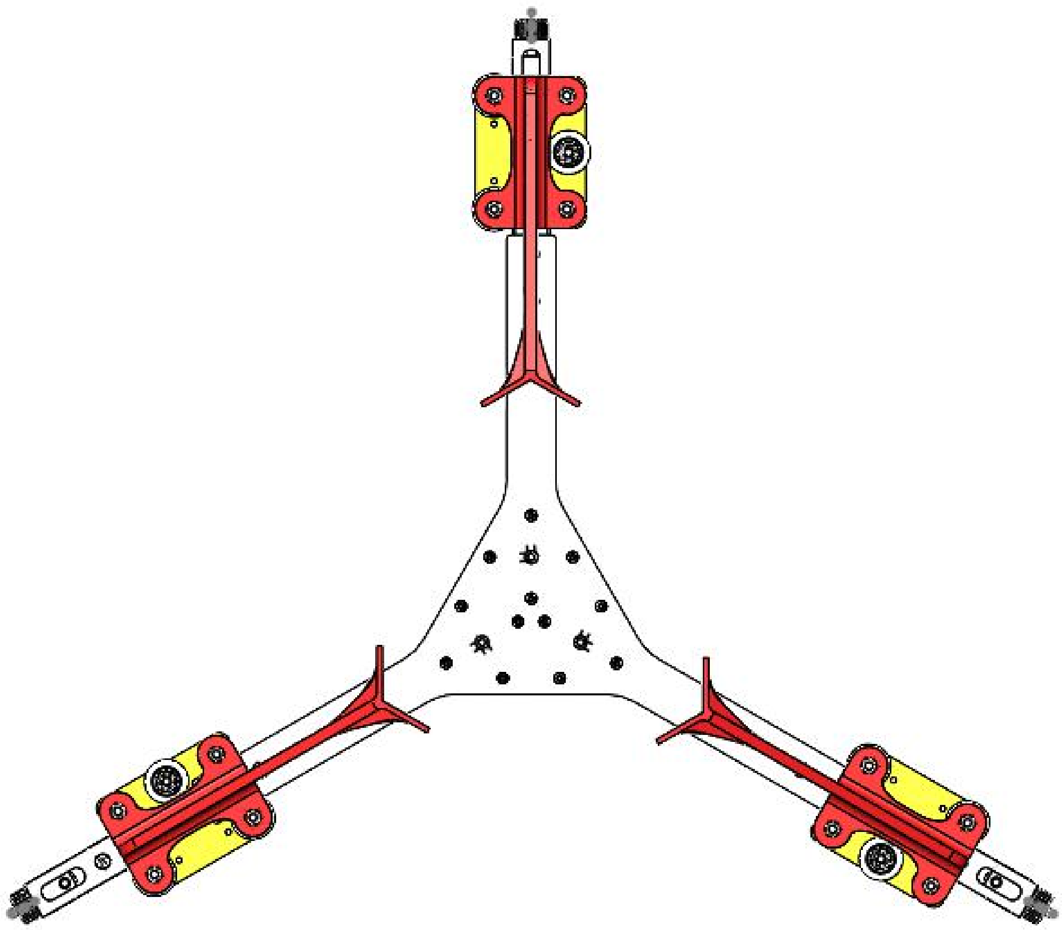


Photo B-9: Linear Actuator from Top View